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## GOLDSCHMIDTINE, A NEWLY RECOGNIZED ANTIMONIDE OF SILVER

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### INTRODUCTION

The numerous early analyses of natural antimonial silvers listed by Hintze (1904, p. 429) give silver values ranging from 71.52 to 84 per cent. Several of these analyses correspond well to the composition  $\text{Ag}_3\text{Sb}$  (72.7 per cent Ag), which is the generally accepted formula for the mineral dyscrasite. The correctness of this formula has been confirmed by Machatschki (1928) who showed that bladed dyscrasite from Andreasberg in the Harz has the same hexagonal or nearly hexagonal structure as the artificial compound  $\text{Ag}_3\text{Sb}$ . Antimonial silvers with more than 73 per cent Ag, such as the material from Cobalt, Ontario, described by Walker (1921), are inhomogeneous, consisting of dyscrasite and a material with higher silver content.

The crystal form attributed to dyscrasite is orthorhombic, pseudo-hexagonal, with common twinning on (110). The accepted elements:

$$a:b:c=0.5775:1:0.6718$$

rest on meagre measurements by Hausmann (1847, p. 57), probably made on crystals from Andreasberg. Machatschki noted the fact that Hausmann's elements gave a prism angle of practically  $60^\circ$ , but could find no further relation between the form ascribed to dyscrasite and the hexagonal lattice of natural and artificial  $\text{Ag}_3\text{Sb}$ .

A specimen with well developed crystals, labeled dyscrasite from Andreasberg (Harvard Mineralogical Museum, 81628) offered an opportunity of revising the early crystallographic work on this mineral. Satisfactory goniometric measurements gave orthorhombic elements in fair agreement with Hausmann's values; x-ray measurements confirmed the choice of lattice and defined its dimensions; but a calculation of the cell content, using the formula  $\text{Ag}_3\text{Sb}$  and the specific gravity 9.7—the mean of several concordant published values—gave an unsatisfactory result. Remeasurement of the specific gravity gave a much lower value, namely 6.83; but again an improbable cell content was obtained. Finally, a pure sample was prepared and carefully analysed by F. A. Gonyer who

reported a surprising result: instead of  $\text{Ag}_3\text{Sb}$ , the composition of the mineral proved to be  $\text{Ag}_2\text{Sb}$ , which accounted for the low specific gravity and yielded an integral cell content.

Since there is no question regarding the existence of the mineral with the composition  $\text{Ag}_2\text{Sb}$ , to which the name dyscrasite<sup>1</sup> is firmly attached, it is clear that the morphology attributed to dyscrasite is that of a mineral with the composition  $\text{Ag}_2\text{Sb}$  whose individuality has hitherto not been recognized. With the consent of Frau Geheimrat Goldschmidt, the mineral with the composition  $\text{Ag}_2\text{Sb}$  is named *Goldschmidtine*,<sup>2</sup> in memory of Victor Goldschmidt [1853–1933] of Heidelberg, whose kindly teaching has led three generations of students to an appreciation of the beauties of crystal morphology.

This work was carried out mainly in the Harvard Mineralogical Laboratory on material and with facilities kindly placed at my disposal by Professor Charles Palache. My thanks are also due to Dr. Harry Berman for making an independent determination of the specific gravity of goldschmidtine; to Dr. J. A. Harcourt for assistance in examining polished sections; to Mr. F. A. Gonyer for carrying out the analysis; and to Mr. W. E. Richmond for taking the x-ray photographs.

#### MORPHOLOGY

*Appearance of the crystals.* The specimen from Andreasberg shows groups of goldschmidtine crystals, which are between tin-white and silver-white with bright metallic lustre on fresh surfaces, pale lead-gray and dull when tarnished. The goldschmidtine is associated with abundant poorly crystallized galena, veinlets of silver or antimonial silver and specks of ruby silver in a gangue of calcite.

The crystal groups of goldschmidtine reach 3 mm. in greatest size. Although imperfectly developed, due to mutual interference and contact with the associated minerals, the general shape is easily recognized as that of a short six-sided prism with a broad base, the edges between the prism and the base being truncated by narrow faces. Already in the hand specimen it is clear that the six-sided prisms are not hexagonal individuals, but complex groups of crystals twinned on planes in the prismatic zone. In spite of the generally poor development, good goniometric measurements were obtained from some portions of selected crystal groups. These showed that goldschmidtine is orthorhombic, univer-

<sup>1</sup> New observations confirming and extending Machatschki's data on dyscrasite will be reserved for another communication. These show that dyscrasite differs from the newly recognized mineral in all its essential properties.

<sup>2</sup> Goldschmidtite of Hobbs (1899) was shown by Palache (1901) to be identical with sylvanite.



sally twinned on (110), as described later. With considerable angles between the subparallel faces in twinned relation, it was easy to distinguish the faces of a single individual and thus obtain a projection of the untwinned reciprocal lattice.

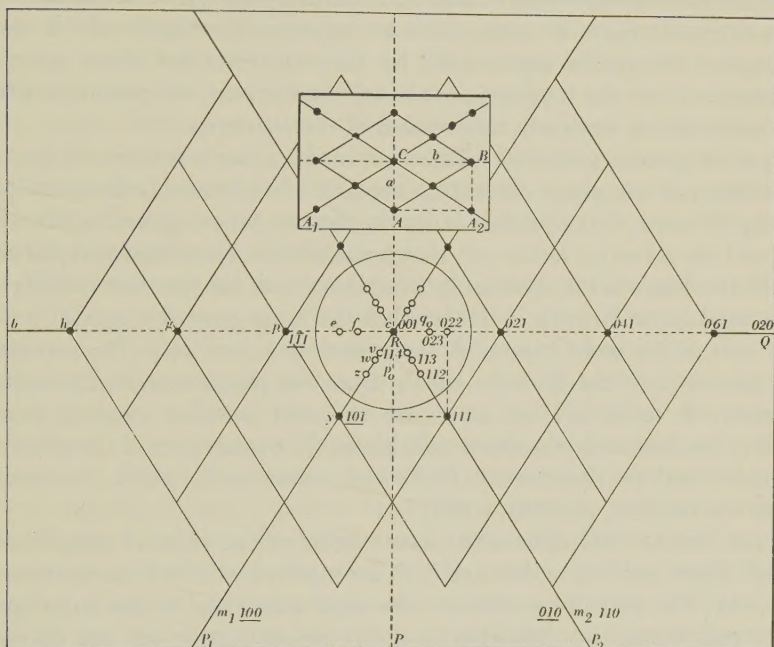


FIG. 1. Goldschmidtine. Gnomonic (reciprocal lattice) projection of the observed forms. The underlined indices refer to the axes  $P_1P_2R$  of the simple (principal) reciprocal lattice cell; the indices not underlined refer to the double (base-centered) reciprocal lattice cell with axes  $PQR$ . The inset shows the corresponding direct lattice, the simple cell with axes  $A_1A_2C$ , the double cell with axes  $ABC$ .

*Determination of the crystal lattice from the crystal form.* This was conveniently done by applying the Harmonic-Arithmetic Rule (1937) to the gnomonic projection of the observed planes. This rule is a rigorous consequence of an idealized form of the Law of Bravais, as applied to the simple structural lattice. It states that, if the relative importance of crystal faces is a direct expression of the relative spacings of the corresponding lattice planes, then the gnomonic projection points of the faces of a zone-quadrant form simultaneous series:

$p$ :	0	...	$\frac{1}{3}$	...	$\frac{1}{2}$	...	1	...	2	...	3	...	$\infty$
$s$ :	0			...	$(\frac{2}{3})$		$\frac{2}{3}$		$(\frac{2}{3})$		$(\frac{2}{3})$	...	$\infty$
$t$ :					...	$\frac{3}{5}$	$\frac{3}{4}$		$(\frac{3}{4})$		$\frac{5}{8}$	...	$\infty$

in which the end-terms represent the planes with the greatest and second greatest spacings while the unit term represents the plane with the third greatest spacing in the quadrant.<sup>3</sup> The primary series ( $p$ ) is always the most strongly developed; the secondary ( $s$ ), tertiary ( $t$ ) and higher series are successively weaker and often entirely absent. The harmonic and arithmetic parts of each series are equally developed only if the spacings of the planes represented by the end-terms are about equal. In general, either the harmonic or the arithmetic part will preponderate with reduction or complete suppression of the other part.

Figure 1 gives a gnomonic projection of the observed forms of goldschmidtine on the plane normal to the axis of the main (prismatically developed) zone. Our problem is, in the first instance, to find what we shall call the *principal lattice cell*, that is the lattice cell whose axial planes are the three sets of non-coaxial lattice planes with the greatest spacings. From the Law of Bravais it follows that the main zone of a crystal contains two of the axial planes of the principal lattice cell. The vertical axial planes must therefore be chosen from the planes  $m_1 m_2 b$ . Since the symmetry is orthorhombic,  $m_1 m_2$  are the only possible vertical axial planes;  $c$  is necessarily the third axial plane. The polar axes of the principal lattice cell are therefore  $P_1 P_2 R$ , with reference to which the axial planes are  $m_1(100)$ ,  $m_2(010)$ ,  $c(001)$ .<sup>4</sup>

It remains to determine unit planes defining the relative lengths of the cell-edges; and since the axes  $P_1 P_2$  are equivalent it suffices to determine, say, the unit plane (101) in the axial zone  $[cm_1]$  of the principal lattice cell. From the definition of the principal lattice cell the planes with the greatest spacings in the zone quadrant  $[cm_1]$  are  $c(001)$  and  $m_1(100)$ ; the plane with the third greatest spacing is (101). Inspecting the zone series  $c-m_1$  in the gnomonic projection we see at once that  $y$  is the only admissible unit term. With  $c-y$  as unit length we have a regular primary series in which the harmonic part alone is present:

	$c$	$v$	$w$	$z$	$y$	$m$
$p:$	0	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$	1	$\infty$

The plane  $y$  is therefore the plane with the third greatest spacing in the zone quadrant and consequently it is the plane (101) of the principal lattice cell. Thus the structural lattice is completely defined. Confirmation is given by the zone series  $c-b$  where  $p$  is the unit term of a regular primary series in which the harmonic and arithmetic parts are equally developed:

<sup>3</sup> The derivation of these ideal series from the Law of Bravais was outlined to the Mineralogical Society of America at the meeting in 1936. A similar derivation with further study of zonal series has recently been given by Donnay (1938).

<sup>4</sup> In figure 1 indices referring to the principal lattice cell are underlined.



	<i>c</i>	<i>f</i>	<i>e</i>	<i>p</i>	<i>g</i>	<i>h</i>	<i>b</i>
<i>p</i> :	0	$\frac{1}{3}$	$\frac{1}{2}$	1	2	3	$\infty$

The plane *p* is therefore the unit plane ( $\bar{1}\bar{1}1$ ) in the principal lattice cell.

The harmonic-arithmetic rule thus yields an unequivocal determination of the simple reciprocal structural lattice, whose first layer is given by the net in full lines carrying the filled points (*hkl*) at its nodes. The direction lines to the vertical planes are parallel to vectors leading from the origin (000) to zero-layer points (*hk*0); the blank points are points in which vectors joining the origin (000) to higher layer points (*hkl*) intersect the plane of the first layer (plane of the gnomonic projection). The inset in figure 1 shows the corresponding direct lattice with *A*<sub>1</sub> *A*<sub>2</sub> *C* as the axes of the principal lattice cell.

With reference to the rectangular reciprocal lattice cell, with axes *P Q R* (dotted in figure 1) and elements *p*<sub>0</sub>:*q*<sub>0</sub>:*r*<sub>0</sub> there is systematic absence of points not conforming to the law, (*h*+*k*) even; the direct rectangular lattice cell, with axes *A B C* (dotted in the inset, figure 1) and elements *a*:*b*:*c*, is therefore base-centered (*C*). Since we recognize the faces of a crystal as planes of the crystal lattice, and see a direct relation between the relative importance of crystal faces and the relative spacing of lattice planes (and the intimately connected relative simplicity of indices), the indices used to describe the forms of a crystal must surely conform to the mode of the lattice. The indices of the observed forms of goldschmidtine are therefore as given in Table 1, in which the indices of only two forms, *b*{020} and *e*{022} must be written in multiple form to give (*h*+*k*) even. In both cases the resulting reduced spacing and increased complexity of indices is in keeping with the relative importance of the form.

It is now of interest to compare the form list of goldschmidtine with a list of lattice planes and spacings extending from (001), with the greatest spacing in the lattice, to (061), the observed plane with the least spacing (Table 1). The spacings were determined by a rapid graphical method described elsewhere (1938), the values being given in absolute units based on the value *c*<sub>0</sub>=8.42 Å subsequently obtained by x-ray measurement.

In excellent agreement with the Law of Bravais, the most important forms of goldschmidtine, *c m b p y*, correspond to the most widely spaced planes of the lattice; the remaining observed forms (with letters), and some further forms (with queries) attributed to dyscrasite (Goldschmidt, 1916) but probably observed on goldschmidtine, are separated by increasing gaps in the list. These gaps do not affect the choice of lattice, which is amply confirmed by the arrangement of the principal forms;

TABLE 1. GOLDSCHMIDTINE: SPACINGS OF PLANES IN THE BASE-CENTERED LATTICE

<i>Form</i>	<i>hkl</i>	<i>d</i> (Å)	<i>Form</i>	<i>hkl</i>	<i>d</i> (Å)	<i>Form</i>	<i>hkl</i>	<i>d</i> (Å)
<i>c</i>	001	8.42	—	221	3.05	—	203	2.27
<i>m</i>	110	6.57	<i>g</i>	041	2.89	—	151	2.26
<i>b</i>	020	6.16	?	202	2.85	?	133	2.21
<i>y</i>	111	5.17	—	132	2.75	—	312	2.16
<i>p</i>	021	4.96	<i>w</i>	113	2.58	—	223	2.13
?	200	3.88	<i>f</i>	023	2.55	—	331	2.11
—	201	3.77	—	310	2.53	—	242	2.08
?	130	3.60	—	311	2.41	—	043	2.07
<i>z</i>	112	3.55	?	240	2.41	—	152	2.04
<i>e</i>	022	3.47	?	150	2.35	<i>v</i>	114	2.01
—	131	3.32	—	241	2.31	<i>h</i>	061	1.99

they do, however, represent departures from perfect correspondence between form-importance and lattice spacing. One might, therefore, fairly ask: If the Harmonic-Arithmetic Rule follows rigorously from the idealized Law of Bravais, why is the Rule strictly satisfied in the present case whereas the Law is only approximately true? This is easily understood if we regard the departures from perfect agreement between form importance and lattice spacing not as under-development of certain expected planes but as over-development in certain zones. As may be seen in Table 1 all the observed planes after *p* lie in the two important zones [100] and [1 $\bar{1}$ 0]. This over-development simply extends these zonal series, thereby adding precision to the selection of the unit term. And thus we see that over-development in certain zones, a frequent departure from ideal correspondence between form-importance and lattice spacing, is a help rather than a hindrance in finding the crystal lattice by means of the serial expression of the Law of Bravais.

*Elements and angles.* The best goniometric measurements give the following geometrical elements for goldschmidtine:

$$p_0:q_0:r_0=1.0868:0.6860:1$$

$$a:b:c=0.6312:1:0.6860$$

Hausmann's elements, supposed to have been obtained on dyscrasite:

$$a:b:c=0.5775:1:0.6718$$

are only roughly similar to the new values. A comparison of angles is perhaps more significant:

	Hausmann	Peacock
(110):(1 $\bar{1}$ 0)	60°01'	64°31'
(001):(011)	33 54	34 27



The angles  $(001):(011)$  and consequently the ratios  $b:c$  are fairly close; the considerable difference in the angles  $(110):(\bar{1}\bar{1}0)$  and therefore in  $a:b$ , is very probably due to Hausmann's having taken this value as  $60^\circ$  for lack of a good measurement, whereas the true angle actually departs from  $60^\circ$  by  $4\frac{1}{2}^\circ$ .

The forms attributed to dyscrasite (Goldschmidt, 1916) are also those of goldschmidtine. Of the twelve forms observed in the present work,  $c\{001\}$ ,  $b\{010\}$ ,  $m\{110\}$ ,  $e\{011\}$ ,  $p\{021\}$ ,  $z\{112\}$ ,  $y\{111\}$ , are given for dyscrasite. The remaining forms ascribed to dyscrasite,  $a\{100\}$ ,  $n\{120\}$ ,  $q\{130\}$ ,  $r\{150\}$ ,  $d\{101\}$ ,  $x\{332\}$ ,  $s\{133\}$ , are also probable forms of goldschmidtine, the indices of the more complex forms,  $q, r, x, s$ , conforming to the base-centered condition,  $(h+k)$  even. Finally, the oft repeated figure representing dyscrasite is a typical goldschmidtine combination:  $c\ b\ m\ p\ z\ y$ . It is evident, therefore, that the early crystallography of antimonial silver was based on crystals with the composition  $\text{Ag}_2\text{Sb}$  while the early analyses were made on dyscrasite, or mixtures of antimonial silvers of higher average silver content.

Table 2 gives a summary of the best measurements on goldschmidtine and the corresponding calculated two-circle and interfacial angles. The angles  $A, B, C$  have the following significance:

$$A = (hkl):(100); B = (hkl):(010); C = (hkl):(001)$$

TABLE 2. GOLDSCHMIDTINE— $\text{Ag}_2\text{Sb}$ Orthorhombic— $C$ ; disphenoidal—222

$$a:b:c=0.6312:1:0.6860; p_0:q_0:r_0=1.0868:0.6860:1$$

Forms	Measured		Calculated			
	$\phi$	$\rho$	$\phi$	$\rho=C$	$A$	$B$
$c\ 001$	—	$0^\circ 00'$	—	$0^\circ 00'$	$90^\circ 00'$	$90^\circ 00'$
$b\ 020$	$0^\circ 00'$	$90\ 00$	$0^\circ 00'$	$90\ 00$	$90\ 00$	$0\ 00$
$m\ 110$	$57\ 44$	$90\ 00$	$57\ 44\frac{1}{2}$	$90\ 00$	$32\ 15\frac{1}{2}$	$57\ 44\frac{1}{2}$
$f\ 023$	$0\ 00$	$25\ 15$	$0\ 00$	$24\ 34\frac{1}{2}$	$90\ 00$	$65\ 25\frac{1}{2}$
$e\ 022$	$0\ 00$	$34\ 25$	$0\ 00$	$34\ 27$	$90\ 00$	$55\ 33$
$p\ 021$	$0\ 00$	$53\ 55$	$0\ 00$	$53\ 55$	$90\ 00$	$36\ 05$
$g\ 041$	$0\ 00$	$70\ 46$	$0\ 00$	$69\ 58\frac{1}{2}$	$90\ 00$	$20\ 01\frac{1}{2}$
$h\ 061$	$0\ 00$	$76\ 00$	$0\ 00$	$76\ 20\frac{1}{2}$	$90\ 00$	$13\ 39\frac{1}{2}$
$v\ 114$	$57\ 50$	$18\ 09$	$57\ 44\frac{1}{2}$	$17\ 48\frac{1}{2}$	$75\ 00\frac{1}{2}$	$80\ 36$
$w\ 113$	$57\ 44$	$23\ 39$	$57\ 44\frac{1}{2}$	$23\ 11\frac{1}{2}$	$70\ 33$	$77\ 52$
$z\ 112$	$57\ 43$	$32\ 43$	$57\ 44\frac{1}{2}$	$32\ 43\frac{1}{2}$	$62\ 48$	$73\ 13\frac{1}{2}$
$y\ 111$	$57\ 44$	$52\ 10$	$57\ 44\frac{1}{2}$	$52\ 07$	$48\ 08$	$65\ 05$

The good agreement between the mean measured and calculated angles for the common forms,  $m\ e\ p\ z\ y$ , shows that the geometrical elements are sufficiently precise.

*Character of the forms.* The following notes describe the frequency and quality of the observed forms.

$c\{001\}$ : large on most crystals; surface good; usually faintly striated along  $[110]$  as a result of poor cleavage or parting on  $(110)$ ; separate segments in twinned groups usually slightly displaced from true parallelism due to slight misfit of twinned parts.

$b\{020\}$ : large on all crystals; surface poor, but gives good azimuth readings; always distinctly striated along  $[100]$  or stepped by oscillatory combination with planes  $(0kl)$ .

$m\{110\}$ : large on most crystals; surface good; always faintly striated in an oblique direction by very narrow planes  $(hkl)$ ; oblique striations often symmetrical to a plane  $(001)$  passing through the middle of the crystal.

$f\{023\}$ : observed twice as a very narrow face.

$e\{022\}$ : fairly common as a good narrow face.

$p\{021\}$ : on all crystals as a good face; usually wider than  $e$ .

$g\{041\}$ ,  $h\{061\}$ : rare and usually narrow.

$v\{114\}$ ,  $w\{113\}$ : each observed three times as narrow faces of fair quality.

$z\{112\}$ ,  $y\{111\}$ : common and often well developed;  $y$  usually wider than  $z$ .

As already mentioned the further forms ascribed to dyscrasite were probably observed on goldschmidtine:

$$a\{200\}, r\{150\}, q\{130\}, n\{240\}, d\{202\}, x\{332\}, s\{133\}$$

These may be retained subject to confirmation.

*Twinning and crystal class.* Crystals of goldschmidtine are all twinned by reflection and composition on the planes  $(110)$  or  $(1\bar{1}0)$ . Twinning on this law results in complete restoration of the crystal lattice with some deviation at the twinning plane (Fig. 9). The obliquity of the twin, given by the angle between the normal to the twin plane  $(110)$  and the quasi-normal lattice row  $[310]$  is  $4^\circ 25'$ , which is larger than the values usually found in this common type of twinning. Planes of  $b\{020\}$  on the normal individual and  $m\{110\}$  on the twinned individual make the calculated angle  $6^\circ 46'$ , as compared with the mean angle  $6^\circ 43'$  from four measurements. Planes of  $e\{022\}$  and  $z\{112\}$ ,  $p\{021\}$  and  $y\{111\}$ , and other pairs likewise come into subparallel position on the two individuals. In the valuable explanatory terminology of Friedel (1926, p. 421) this twin law is an example of *twinning by pseudo-merohedry*. This designation conveys the fact that the crystal (orthorhombic) is pseudo-merohedral (pseudo-hexagonal) and therefore predisposed to twin on the elements of hexagonal pseudosymmetry.

Twinning on  $(110)$  is rarely simple. Sometimes it is repeated on parallel planes giving successive plates alternately in normal and twinned positions; occasionally the twinning is truly lamellar in some parts of



the intergrowth. More commonly the twinning takes place on both planes of  $\{110\}$ , giving a variety of cyclic intergrowths similar to the well known twinned groups of aragonite. As shown in Fig. 9 the "misfit" on a cyclic group of three individuals is considerable. Theoretically this gives a pronounced gap, or overlap, according to the arrangement of the intergrowths. Actually such misfits are covered by irregular growths. Although the patterns of the groups can be easily distinguished the crystal groups are always more or less malformed.

In addition to the very evident twinning on (110) goldschmidtine shows evidence of twinning on other laws which have important bearing on the crystal class. The already mentioned symmetrical oblique striations on  $m\{110\}$ , shown in Fig. 8 and frequently visible, are perhaps possible in the holohedral class; but in crystals attached at one end of the vertical axis they rather suggest twinning on (001). More convincing is a notching of the edges [100] by terminal planes in symmetrical relation to (100), illustrated in Figs. 6 and 7; this was observed several times, and it can be explained only by twinning on (100). If (001) and (100) are twinning planes they cannot be symmetry planes of the crystal. In the orthorhombic system the absence of two symmetry planes excludes both the dipyramidal and pyramidal classes and admits only the disphenoidal class—222.

Twinning on a symmetry element of the crystal lattice which is not a symmetry element of the crystal structure was termed *twinning by merohedry* by Friedel. As shown in Fig. 10 such twinning precisely restores the lattice (obliquity zero), whereas the merohedral structure, indicated by two points with only disphenoidal symmetry in each cell, is brought into reflection relation. Since the lattices of the two individuals fit equally well on any junction surface the complete irregularity of this surface in most twins by merohedry is easily understood. As the obliquity is zero we should expect that the twinning would be difficult to detect, especially if the twinned parts are equally developed or intimately intergrown. Under these conditions it is also difficult or impossible to distinguish the complementary merohedral forms. Such is the case with goldschmidtine in which a distinction between right and left disphenoids is not practicable.

The final step in the morphological study is to attempt to determine the space group from Donnay and Harker's generalization of the Law of Bravais (1937). As a better approximation than the Law of Bravais, the generalization states that the importance of crystal planes is proportional to the effective spacings of the corresponding lattice planes, as defined by the lattice parameters and the simplest indices conforming to the general extinctions of the space group.

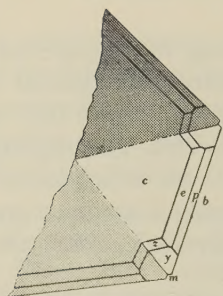


FIG. 2

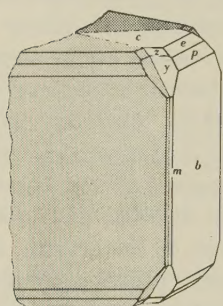


FIG. 3

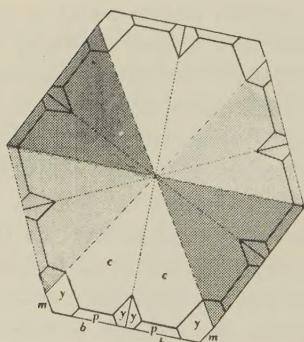


FIG. 6

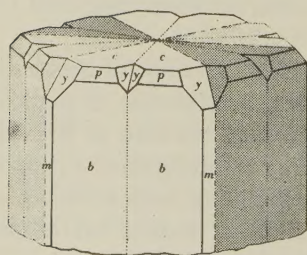


FIG. 7

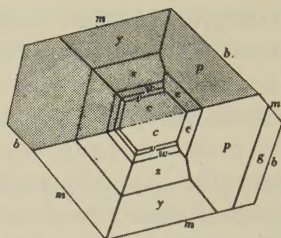


FIG. 4

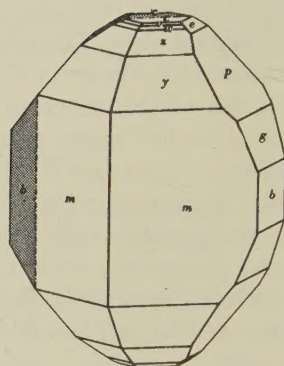


FIG. 5

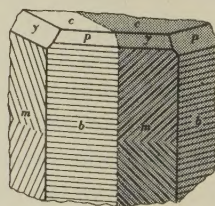


FIG. 8

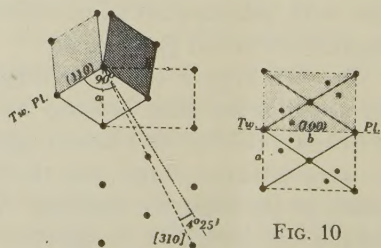


FIG. 9

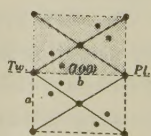


FIG. 10



## EXPLANATION OF FIGURES 2-10.

FIGS. 2, 3. An incomplete cyclic group resulting from twinning on  $(1\bar{1}0)$  and  $(\bar{1}10)$ , showing the commonly large development of  $c$  and  $b$ .

FIGS. 4, 5. Twin on  $(\bar{1}10)$  with unusually large development of terminal planes.

FIGS. 6, 7. A cyclic group (restored) showing twinning on  $(1\bar{1}0)$  and  $(\bar{1}10)$  and also twinning on  $(100)$ .

FIG. 8. Fragment of a twin showing the usual juxtaposition of a horizontally striated plane  $b$  on one individual and an obliquely and symmetrically striated plane  $m$  on the other individual.

FIG. 9. The direct lattice twinned by pseudomerohedry on  $(110)$  and  $(1\bar{1}0)$  with obliquity  $4^\circ 25'$ .

FIG. 10. The direct lattice twinned by merohedry on  $(100)$ , bringing a schematically represented disphenoidal structure into reflected position.

In the disphenoidal class there are only two space groups in a one-face centered lattice,  $C222$  and  $C222_1$ . In  $C222$  there is no general condition beyond that imposed by the lattice and the effective spacings are as given in Table 1; in  $C222_1$  a vertical screw axis gives effective halving of the spacing of the basal planes. The importance of  $c\{000\}$  certainly ranks with that of  $m\{110\}$  and  $b\{020\}$  and not after that of  $p\{021\}$  as it should with the halved spacing of  $4.21 \text{ \AA}$ ; therefore we could choose the space group  $C222$ . However, the space group  $C222_1$  is given by the systematic absence of the odd orders of  $(00l)$  in the x-ray photographs. Isolated exceptions do not, of course, invalidate an approximation. It would strengthen the generalized Law of Bravais, however, if it were shown to explain the development of crystal forms better than the classical law in a large number of special cases.<sup>5</sup>

#### STRUCTURE CELL

*Lattice and space group.* On a small crystal of goldschmidtine the following x-ray photographs were taken with copper radiation: rotation, zero-layer and first-layer Weissenberg about  $[001]$ , and a zero-layer Weissenberg about  $[100]$ . The crystal proved to be twinned on  $(110)$ ; but with the considerable obliquity of the twin the diffractions from the two individuals were easily distinguished.

The lattice parameters obtained for the rectangular cell are:

$$a_0 = 7.75 \text{ \AA}, b_0 = 12.32 \text{ \AA}, c_0 = 8.42 \text{ \AA}, \text{ all } \pm 0.05 \text{ \AA} \\ a_0:b_0:c_0 = 0.629:1:0.683$$

in good agreement with the geometrical ratio:

$$a:b:c = 0.6312:1:0.6860.$$

The films showed diffractions  $(hkl)$  only with  $(h+k)$  even, proving the base-centering of the lattice found by morphological study. Furthermore diffractions  $(00l)$  are present only with  $l$  even. In the disphenoidal class these systematic extinctions admit only one space group,  $C222_1$ .

*Specific gravity and cell content.* A small clean crystal (0.1571 gm.) weighed with proper precautions in air and in water, gave the specific gravity:

$$G = 6.83$$

In view of this unexpectedly low value Dr. Berman kindly made an independent determination, using the method of attaching the crystal

<sup>5</sup> Since this was written Dr. Donnay has added great weight to the generalized law of Bravais, in a paper read to the Mineralogical Society of America, December, 1938: Crystal space-groups determined without x-rays (Abstract in *Am. Mineral.*, **23**, no. 12, part 2, p. 5, 1938).



(0.0065 gm.) to a small glass rod and suspending the whole in a heavy liquid. The value thus obtained was 6.7. With the higher specific gravity the molecular weight of the contents of the base-centered cell is:

$$M_C = 3328$$

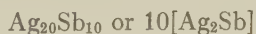
On a clean sample of crystal fragments (0.34 gm.) Mr. Gonyer reported the values in the first column of Table 3.

TABLE 3. GOLDSCHMIDTINE: COMPOSITION AND CELL CONTENT

	1	2	3	4	5
Ag	64.78	0.6488	0.006013	20.01	63.9
Pb	0.00	—	—	—	—
As	0.00	—	—	—	—
Cu	0.00	—	—	—	—
Sn	0.00	—	—	—	—
Sb	35.01	0.3506	0.002896	9.64	36.1
S	0.06	0.0006	0.000019	0.06	
	99.85	1.0000			100.0

1. Goldschmidtine, Andreasberg, Harz; anal. F. A. Gonyer. 2. Weight proportions summing to unity. 3. Atomic proportions. 4. Atoms in the cell with molecular weight 3328. 5. Percentage composition of  $\text{Ag}_2\text{Sb}$ .

As shown in the fourth column, Table 3, the content of the base-centered cell closely approaches:



The calculated specific gravity is:

$$G_0 = 6.92$$

#### CHEMICAL CONSIDERATIONS

The composition  $\text{Ag}_2\text{Sb}$  has been mentioned in the past as one of many possible silver-antimony compounds. Rammelsberg (1875, p. 26) notes that Domeyko obtained 64 per cent Ag on material from Chancarcillo, Chile. If this material was a homogeneous silver-antimony mineral it was presumably goldschmidtine. Following earlier systematists, Groth (1874, p. 14) also suggested the composition  $\text{Ag}_2\text{Sb}$  on the basis of a supposed analogy between the silver mineral and chalcocite. Since there is no simple structural relation between goldschmidtine and chalcocite this speculation is without significance.

The silver-antimony equilibrium diagram (Guertler, 1913, p. 769)

shows only one compound,  $\text{Ag}_3\text{Sb}$  (dyscrasite) which crystallizes at  $560^\circ$ . This indicates that  $\text{Ag}_2\text{Sb}$  does not form from fusion conditions. To test this a crystal was heated in a partial vacuum for 15 minutes at  $520^\circ$  to  $530^\circ$ . The crystal melted and, on cooling, solidified to a black bead which gave an  $x$ -ray powder photograph not resembling a powder diagram of goldschmidtine. The crystal had evidently dissociated to a mixture of phases as predicted by the equilibrium diagram in the region corresponding to the composition  $\text{Ag}_2\text{Sb}$ .

#### PHYSICAL PROPERTIES

Goldschmidtine has no good cleavage. A difficult separation, probably a parting, was obtained parallel to (110). The cleavages {001} and {011} attributed to dyscrasite seem to have been based on the striations noted on goldschmidtine. The hardness is  $2\frac{1}{2}$ , which is notably lower than the hardness  $3\frac{1}{2}$ –4, given for dyscrasite.

Polished sections were made of a single crystal group and of fragments from the sample used for analysis. The mineral is homogeneous, tin-white inclining to silver-white; distinctly anisotropic in the crystal section, which was cut roughly parallel to [001]. A polished section of antimonial silver from Cobalt, Ontario, was examined for comparison. The section showed anisotropic dyscrasite, verified by an  $x$ -ray powder photograph which conformed exactly to Machatschki's data (1928), and a lighter isotropic material which is presumably silver with some antimony in solid solution. In separate specimens no clear difference could be noticed in the appearance of goldschmidtine and dyscrasite in reflected light.  $X$ -ray powder photographs on samples extracted with the useful micro-drill devised by Harcourt (1937) afford a sure means of distinction.

#### SUMMARY

Goldschmidtine— $\text{Ag}_2\text{Sb}$ , is a distinct mineral hitherto confused with dyscrasite— $\text{Ag}_3\text{Sb}$ . Lattice: orthorhombic; base-centered. Class: disphenoidal. Geometrical elements:  $a:b:c=0.6312:1:0.6860$ . Forms:  $c\{001\}$ ,  $b\{020\}$ ,  $m\{110\}$ ,  $f\{023\}$ ,  $e\{022\}$ ,  $p\{021\}$ ,  $g\{041\}$ ,  $h\{061\}$ ,  $x\{114\}$ ,  $w\{113\}$ ,  $z\{112\}$ ,  $y\{111\}$ . Habit: stout prismatic with  $c$   $b$   $m$  dominant. Twinning: on (110), also on (100) and (001). Space group:  $C222_1$ . Base-centered structure cell:  $a_0=7.75 \text{ \AA}$ ,  $b_0=12.32 \text{ \AA}$ ,  $c_0=8.42 \text{ \AA}$ , all  $\pm 0.05 \text{ \AA}$ ;  $a_0:b_0:c_0=0.629:1:0.683$ ; contains  $\text{Ag}_{20}\text{Sb}_{10}$ . Cleavage: none; parting (?) {110}. Hardness:  $2\frac{1}{2}$ . Specific gravity: 6.83 (meas.); 6.92 (calc.). Tin-white to silver-white with metallic lustre; lead-gray when tarnished. Polished surfaces homogeneous, anisotropic. Analysis (Gonyer): Ag 64.78, Sb 35.01, S 0.06=99.85. Occurrence: with galena, native silver



or antimonial silver and ruby silver, in calcite on a specimen from Andreasberg, Harz. Name: after Victor Goldschmidt [1853-1933] of Heidelberg.

Goldschmidtine is used to exemplify the method of determining the structural lattice from the crystal form, by applying the Harmonic-Arithmetic Rule to the gnomonic projection of the observed forms.

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# THE ROSEBUD METEORITE, MILAM COUNTY, TEXAS

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## INTRODUCTION

The details of the history of the Rosebud meteorite are somewhat obscure. It was presented to the University of Texas by Captain J. W. Waters on May 11, 1915, and accepted by Dr. F. W. Simonds on behalf of the Department of Geology. According to a news item appearing in the *Austin Statesman* on May 11, 1915, the meteorite was seen to fall from the sky about 8 years previously and was afterwards plowed up by a field hand on Captain Waters' plantation. Its weight was given as 125 pounds. On making inquiry\* in the vicinity of Rosebud it was learned that the meteorite was fairly well known in the neighborhood and at one time had been used as a hitching stone in front of a drug store in Rosebud.

Some of the older inhabitants of the neighborhood reported that the meteorite fell in the early morning "about 25 or 30 years ago." Others, however, who were living near by have no recollection of the fall whatever. The meteorite was found about 1.5 miles west of the little community of Burlington in northern Milam County. Burlington is in central Texas about 25 miles east of Temple, Texas. It might seem more appropriate to have called the meteorite the Burlington but since this name is preoccupied, the name Rosebud is applied to it, although the town of Rosebud is some six miles to the north and across the county line in Falls County. It seems doubtful whether this meteorite can be classified as an observed fall and it is therefore listed as a find dating from about 1907. Since 1915 the meteorite has been in the collections of the University of Texas and until a year or so ago in charge of Dr. F. W. Simonds, to whom the writer is indebted for the opportunity to study it.

## EXTERNAL FEATURES OF THE METEORITE

The Rosebud Meteorite is a cone-shaped mass having a weight of 54.9 kilograms ( $121\frac{1}{4}$  pounds). The diameter of the mass at the base is approximately 18 inches and the maximum height is 11 inches. The specific gravity as determined with a Jolly balance is 3.59.

The specimen is a rather perfect conoid-shaped mass with a smooth nose or "brustseite" from which oval shaped pittings radiate in all directions. The smooth nose is on the apex of the mass but consists of two

\* The writer is indebted to Mr. Oscar Monnig of Ft. Worth, Texas, for the details of the history of the Rosebud Meteorite in the vicinity of Rosebud.





FIG. 1. Side view showing conoid shape, pitted surface, and smooth apex or "brustseite."



FIG. 2. Top view showing smooth apex and radial arrangement of pittings.

areas separated by a depression. It appears that the nose may have occupied a much larger area but the radial pittings encroached on the nose and destroyed all but the two areas remaining. One half of the front side is an almost perfect cone with the pittings all uniform in size and distribution. The pits are roughly oval in outline with the length about three times the width. The individual pits merge into one another. They rarely exceed one inch in length and are usually 0.15 inch or less in depth. The other half of the front side is more irregular in shape and while it

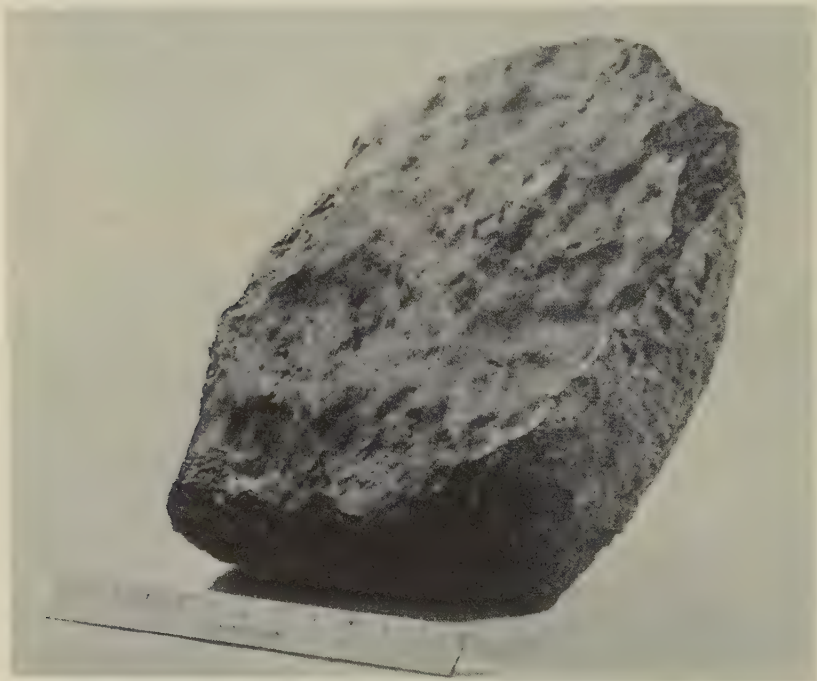


FIG. 3. Rear view showing flat surface with broad shallow pittings and blebby crust.

is completely covered with pittings, similar to those on the other half, they are not as definitely oriented, and in addition there are several deep pits, the largest of these is rudely oval in outline with a length of 2 inches and a depth of 1.5 inches (Figs. 1 and 2).

The rear side is, in general, flat with broad shallow pittings roughly round in outline with a diameter of about 5 inches and a depth of one inch. The depressions merge into one another and superimposed on the larger depressions are many smaller ones which give the surface a pebbly appearance. The crust on the rear surface is distinctly blebby (Fig. 3).



The color of the outer surface is brownish black, the brownish color evidently resulting from the oxidation of the crust. The interior of the specimen is a dull black to grayish black in color. The crust is quite thin although it appears to be somewhat thicker on the rear surface than on the front surface. In breaking off chips of the specimen many fracture lines are evident and along these fractures is a coating of reddish brown iron oxide, probably the result of weathering.

#### STRUCTURE

From a study of thin sections the specimen is observed to be crystalline, with only a minor amount of glass. The structure consists of many chondrules in a matrix of silicate minerals, metal and troilite. The chondrules are relatively larger than the matrix and in this respect the structure of the whole is somewhat porphyritic. Most of the chondrules are broken (fragments of larger chondrules) and the specimen as a whole might well be considered a chondrule breccia. The various types of chondrules are cemented together in a matrix of silicate minerals but definite movement after consolidation is indicated by faulted chondrules and many chondrules and crystals are abruptly terminated by fracture lines. Only a few chondrules are perfect, most of them being irregular in shape and fragmental. A rather large variety of chondrules is present for a single meteorite. The various types of chondrules are as follows:

1. Olivine chondrules of the monosomatic barred type consisting of laminae of olivine, roughly parallel but not in continuous bands. Some are almost perfectly round, or are partly round, but the majority are irregular-shaped fragments. In most cases the optical orientation of the various laminae are not all the same in a single chondrule. The chondrules range in diameter from 0.3 mm. to 1.5 mm. (Fig. 4, No. 4). Many of the chondrules are apparently fragments of much larger masses.

2. Polysomatic chondrules of euhedral olivine with fragments of different optical orientation and orthorhombic pyroxene. There is a tendency for the crystals to be oriented with their long axes parallel to the circumference of the chondrule. The space between the olivine crystals is filled with fibrous orthorhombic pyroxene and a small amount of glass (Fig. 4, No. 3). In some of the chondrules small grains of chromite (?) are quite abundant. In general metal is rare in the chondrules but is abundant in the matrix surrounding the chondrules.

3. Monosomatic chondrules of barred olivine with a rim of olivine forming a border. The rim is usually optically continuous with the olivine of the interior. Metal encroaches slightly on the chondrule but in general is far more abundant in the matrix. One chondrule of this type is faulted

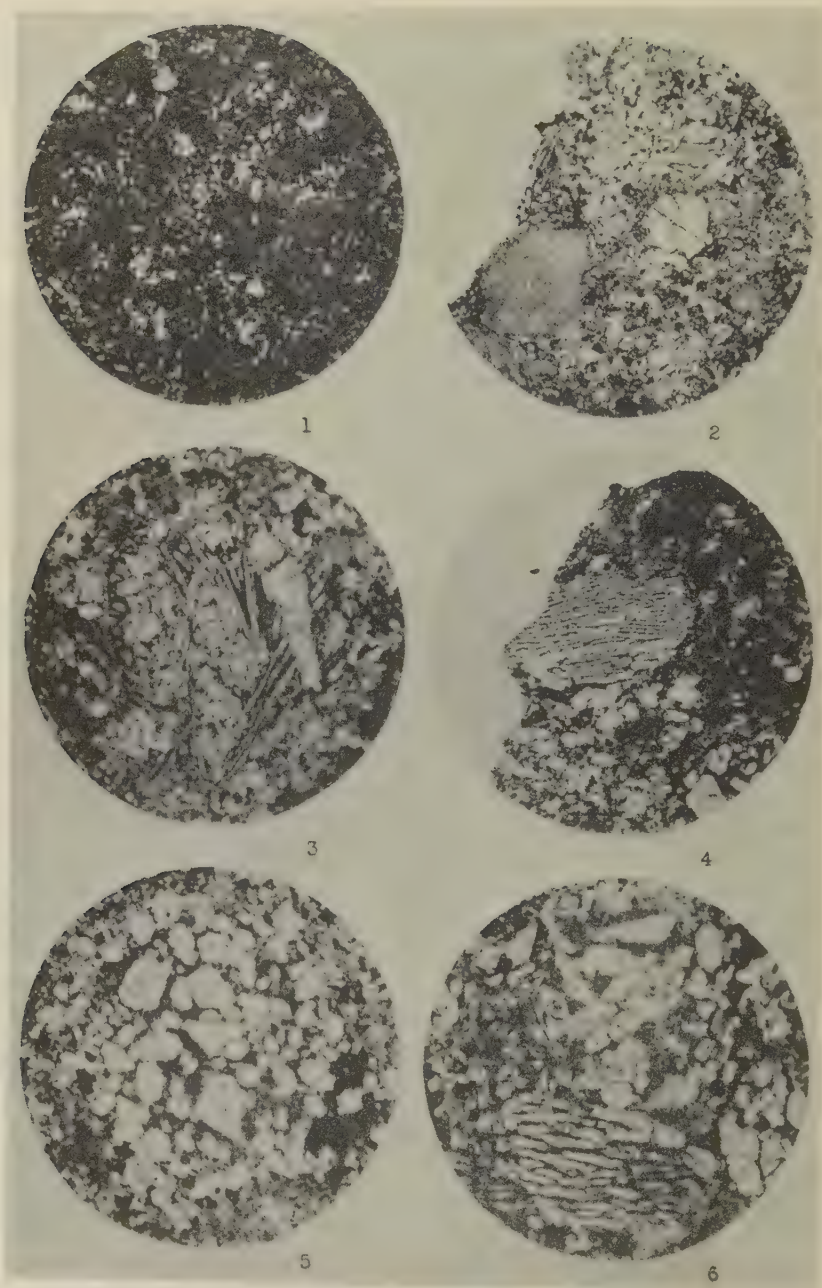


FIG. 4.

## EXPLANATION OF FIGURE 4.

1. Photomicrograph by reflected light showing distribution of metal. The larger metallic fragments (light areas) have a diameter of 0.2 to 0.3 mm.  $\times 10$ .

2. Photomicrograph showing general relation of chondrules and matrix. In the lower left is an irregular chondrule of enstatite. In the upper right is a chondrule composed of fragments of barred olivine. The dark material filling the interspaces is fibrous enstatite. Near the center of the field is a large, somewhat fractured, olivine crystal. Portions of porphyritic olivine chondrules are visible in the lower center and upper center of the field. The dark areas in the field are metal.  $\times 12$ .

3. Long prismatic, orthorhombic pyroxene enclosing euhedral olivine. The dark areas between the pyroxene fibers consist of a structureless, very faintly double refractive substance. The dark color seems to be due to minute dust-like particles of an opaque material.  $\times 25$ .

4. Monosomatic chondrule of barred olivine. The interspaces are filled with granular particles of olivine intermixed with a dark, practically isotropic material. The portion below the wide band is of different optic orientation. The light crystals in the lower part of the field are olivine.  $\times 20$ .

5. Chondrule of porphyritic olivine with interspaces filled with enstatite mixed with unidentified dark opaque specks. A tendency for the crystals on the margin to be oriented with the long axes parallel to the circumference of the chondrule is noticeable. The chondrule grades rather imperceptibly into the matrix. The dark areas are metal.  $\times 45$ .

6. Chondrule composed of fragments of two chondrules. The lower part is barred olivine while the upper part is porphyritic olivine. The dark material filling the spaces between the olivine, in both cases, is fibrous enstatite.  $\times 35$ .



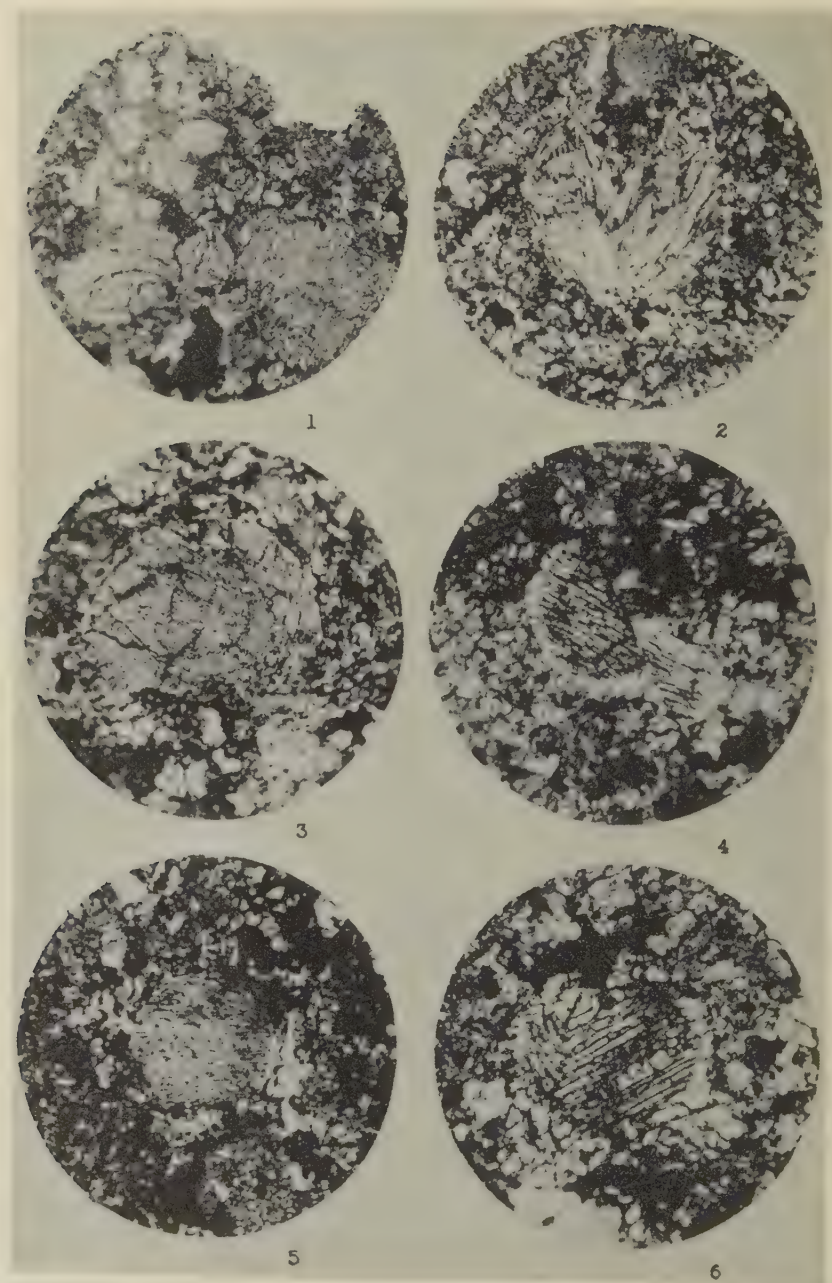


FIG. 5.

## EXPLANATION OF FIGURE 5.

1. Photomicrograph showing two chondrules in contact. The one on the left consists of subhedral fragments of orthorhombic pyroxene enclosed in faintly greenish, fibrous orthorhombic pyroxene. The one in the lower right of the field is enstatite radiating from several centers.  $\times 38$ .

2. Chondrule of orthorhombic pyroxene (hypersthene). The small round mass at the top is radiating enstatite. The light areas in the ground mass are chiefly olivine.  $\times 20$ .

3. Broken chondrule of radiating orthorhombic pyroxene.  $\times 24$ .

4. Faulted chondrule of barred olivine. The rim is in optical continuity with the interior.  $\times 47$ .

5. Round chondrule of orthorhombic pyroxene. The bands are slightly diverging and with the exception of one area the material is all of the same optical orientation. The rim is optically continuous with the adjoining portion of the interior.  $\times 28$ .

6. Twinned chondrule of orthorhombic pyroxene. The rim is optically continuous with the interior.  $\times 80$ .

with a displacement equal to about half the diameter of the chondrule. The faulted chondrule has a diameter of 0.45 mm. (Fig. 5, No. 4).

4. Porphyritic chondrules of euhedral to subrounded crystals of olivine. The olivine is optically negative indicating a rather high percentage of FeO. The individual crystals have a maximum diameter of 0.15 mm. The chondrules, as a whole, are rounded but are not sharply separated from the matrix. The maximum diameter of the chondrules is about 0.5 mm. There is a definite tendency for the olivine crystals to be oriented with their long axes parallel to the circumference of the chondrule, especially along the outer edge of the chondrule. The space between the olivine crystals is filled with fibrous enstatite and glass (Fig. 4, No. 5). Other chondrules consist of a mosaic of variously oriented crystals of olivine fitting close together without any filling of other material between the crystals.

5. Radiate orthorhombic pyroxene chondrules in which the fibers diverge from an eccentric point. Others show a mass of confused fibers or the fibers may form a network due to crossing or interlacing. Some of these chondrules, especially the smaller ones, are almost perfectly round (Fig. 5, Nos. 2, 3, and 5).

6. Chondrules of porphyritic orthorhombic pyroxene in a fibrous matrix of the same material (Fig. 5, No. 1, left side).

Individual crystals of olivine of about the same size as the chondrules also occur. The largest olivine crystal noted has a diameter of 0.6 mm.

In the Rose-Tschermak-Brezina system of classification the Rosebud meteorite would be classified as a Black Chondrite (Csa).

#### MINERALOGY

There is some variation in the relative abundance of the various minerals in different sections so that it is difficult to give a mode for the meteorite with any degree of accuracy. However, in all sections olivine is by far the most abundant mineral making up more than half of the specimen. Metal is next in abundance, followed closely by the pyroxenes (enstatite-hypersthene) with troilite, glass and chromite in relatively small amounts. The actual composition seems to correspond rather closely with the norm given below and the percentages given for the various minerals in the calculated norm is perhaps as close an estimate of the relative abundance as it is possible to make.

*Olivine.*—This mineral occurs as rounded grains, irregular-shaped fragments, and in fairly well developed euhedral crystals. The grains generally occur in the matrix while the fragments and euhedral crystals occur either as phenocrysts or in the chondrules. The olivine is colorless



to slightly yellowish and is similar to that found in terrestrial rocks. It is optically negative with a large axial angle indicating a relatively high FeO content.

*Pyroxenes.*—The pyroxenes are orthorhombic and both enstatite and hypersthene are represented. No monoclinic pyroxenes were identified in thin section. In general the enstatite in chondrules occurs as fibers which radiate from eccentric points. It also occurs in chondrules, usually associated with olivine, in which the enstatite is a mass of confused fibers which have a somewhat netted appearance due to the crossing of the fibers, filling in the space between the olivine. The material is slightly greenish, with low interference colors, parallel extinction, and a very faint pleochroism. The axial angle is quite large and in many cases is so close to  $90^\circ$  that the determination of the sign is impossible. Some fragments occur as isolated masses not associated with chondrules and in many of these a marked polysynthetic twinning is observed. Polysynthetic twinning is also observed on some of the material filling the spaces between olivine bands in olivine-enstatite chondrules. On some of the larger fragments showing polysynthetic twinning, good bisectrix interference figures were obtained which gave a negative sign, indicating hypersthene. It appears, therefore, that both enstatite and hypersthene are present, although an intermediate form with some variation in optical properties might account for the two types observed.

*Metal.*—The metal is rather uniformly distributed throughout the mass, in general, occurring, in irregularly shaped masses ranging from small specks up to 0.5 mm. in diameter. In a few instances the metal is concentrated along veins. In general, the metal is more abundant in the matrix than in the chondrules. In reflected light the metal is of two distinct types, one with a rather dull iron black color and another, in a smaller amount, showing a bright tin white luster.

*Troilite.*—Occurs as bronze-yellow grains irregularly scattered through the mass.

*Glass.*—From the chemical analysis it is apparent that either feldspar (see norm) or glass is present to account for the alumina and alkalis present. Some material, tentatively identified as partially devitrified glass, can be observed in the chondrules and also filling spaces between the silicate minerals in the matrix. An attempt to isolate some of the material with heavy liquids was without success since it is so finely divided and apparently included in other minerals so that no separation was possible. A careful search of a number of thin sections failed to reveal any material which could be identified as feldspar. However, the matrix is rather obscure and in many cases stained with iron oxide so that the positive identification of all the constituents is not possible.

*Chromite*.—In the chondrules are some small black opaque grains which in concentrated light show a reddish border. These are tentatively identified as chromite.

*Schreibersite*.—The analysis of the soluble silicate portion contains the elements present in schreibersite and it is apparent that this mineral is present. It was not identified in thin section.

*Iron oxide*.—The outer edge of the meteorite and extending some distance in from the edge of veins and cracks is a reddish stain which is apparently iron oxide. Its concentration along cracks and veins and on the outer edge of the specimen suggests a secondary origin for the material.

### CHEMISTRY

A chemical analysis of the specimen was made by F. A. Gonyer and is given below:

Metallic portion.....	13.35%
Iron sulphide.....	3.42
Soluble silicate portion.....	44.86
Insoluble silicate portion.....	38.37

	Insoluble Silicates	Soluble Silicates	Metallic Portion	Composite
SiO <sub>2</sub>	54.31	29.98		34.28
TiO <sub>2</sub>	None	None		—
Al <sub>2</sub> O <sub>3</sub>	6.70	2.16		3.53
Fe <sub>2</sub> O <sub>3</sub>	None	Present*		—
Cr <sub>2</sub> O <sub>3</sub>	0.32	0.04		0.14
FeO	9.86	33.46		18.79
MnO	0.23	0.14		0.15
CaO	3.42	1.09		1.80
MgO	23.72	32.70		23.77
NiO	None	0.32		0.14
CoO	None	Trace		Trace
Na <sub>2</sub> O	1.09	—		0.41
K <sub>2</sub> O	0.17	—		0.06
P <sub>2</sub> O <sub>5</sub>	None	0.20		0.09
H <sub>2</sub> O	—	0.17		0.07
FeS	—	—		3.42
Fe	—	—	91.04	12.15
Ni	—	—	8.61	1.15
Co	—	—	0.39	0.05
P	—	—	0.02	0.003
Cu	—	—	Trace	Trace
Mn	—	—	None	—
Sum	99.82	100.26	100.06	100.003

\* From examination of specimen it is quite evident that ferric oxide is present.

The soluble silicate portion of the analysis consists mainly of the olivine of the specimen. The elements contained in schreibersite are present in this portion and in determining this mineral the phosphorus of the analysis was allotted to an appropriate amount of nickel, cobalt and iron to form schreibersite. The ferric oxide, not determined but obviously present, is included with the ferrous iron. The insoluble silicate portion includes the pyroxenes, and the potash, soda, lime and alumina, which on first glance appears to suggest a feldspar, but presumably is present as glass.

A norm calculated from the analysis, according to standard methods, is as follows:

## NORM FOR ROSEBUD METEORITE

Schreibersite.....	0.28
Chromite.....	0.14
Albite.....	0.33
Anorthite.....	7.70
Diopside.....	0.93
Hypersthene.....	9.66
Olivine.....	60.97
Troilite.....	3.42
Metal.....	13.35
	<hr/>
	99.92

The above norm seems to check quite closely with the composition as observed from a study of thin sections, except in the amount of feldspar shown. As previously stated the feldspar indicated in the norm is probably present as glass but from the amount indicated in the norm it should be far more prominent in the thin sections than is actually the case. Also the small amount of diopside shown was not identified in thin section.

A spectrographic analysis of the three portions of the meteorite made by Dr. H. A. Wilhelm, showed the presence of germanium (trace), barium (faint trace), and vanadium (trace), in addition to the constituents reported in the chemical analysis. The complete spectrographic analysis is given below.



	Na	Cu	Mg	Ca	Al	Si	Ge	Co	Cr	Mn	Ni	Fe	Ba	K	Ti	Si	V
Metallic	3	4	3	4	4	3	4	3	4	4	3	1	—	—	—	—	—
Soluble	4	—	2	4	4	2	—	4	5	4	4	3	5	—	—	—	—
Insoluble	2	—	3	4	4	—	—	5	3	4	4	3	—	3	5	2	4

Intensities: 1 strong, 2 present, 3 weak, 4 trace, 5 faint trace.

#### ACKNOWLEDGMENTS

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# OPTICAL AND CHEMICAL STUDIES OF MUSCOVITE

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## ABSTRACT

Twenty-two samples of muscovite were analyzed chemically and their optical constants determined. From these results, the chemical compositions of the end members of the muscovite system were determined and their relation to the optical constants correlated. The chemical formulas for the members of the muscovite system which correspond most accurately with the chemical composition are potassium muscovite ( $\text{H}_4\text{K}_2\text{Al}_6\text{Si}_6\text{O}_{24}$ ), phengite ( $\text{H}_6\text{K}_2(\text{Fe}, \text{Mg})_2\text{Al}_4\text{Si}_6\text{O}_{24}$ ), (new formula), and ferric iron muscovite ( $\text{H}_4\text{K}_2\text{Fe}_2'''\text{Al}_4\text{Si}_6\text{O}_{24}$ ). It was necessary to adopt this new formula for phengite, which contains one more molecule of  $\text{H}_2\text{O}$  and  $\text{FeO}$  or  $\text{MgO}$ , and one less molecule of  $\text{SiO}_2$  than the formula now being used, in order to get satisfactory correlation with the results of the chemical analyses. The ratio of  $\text{R}_2\text{O}$  ( $\text{K}_2\text{O}$  and  $\text{Na}_2\text{O}$ ) to  $\text{SiO}_2$  remains almost constant in all three members at 1 to 6 instead of varying between 1 to 5 and 1 to 8 as suggested by various investigators. When the ferric iron muscovite of the system increases, the refractive index rises. The optic angle decreases with an increase in the amount of phengite, however, the optic angle also decreases when small amounts of phengite are present with large amounts of ferric iron muscovite.

## INTRODUCTION

This paper reports the results of an investigation of the optical properties and chemical composition of the muscovite system. The literature contains many studies bringing out the relationship of the optics of muscovites to their chemistry, but there is lack of complete agreement on the formulas to be assigned to the component end members. A modified formula for phengite is suggested here.

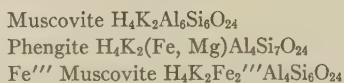
If the composition of muscovite is expressed on the basis of the constituent molecules instead of on the basis of the oxides, the variation in optical properties is more easily understood. This method has been employed effectively by others and is followed here, leading to three end member molecules. Our interest centers on the formulas to be assigned to these molecules.

## PRESENT THEORIES

As early as 1879 Tschermak (10) pointed out that a number of muscovite samples contained more silica than is required by the general formula given to this mica. These high silica micas were designated "phengite" and often have a small optic angle. Along this same line Winchell (13)

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has published a summary of many analyses of muscovite and has concluded that the muscovite system has three end members, one of which accounts for the high silica. He gives the following formulas for this system:



The phengite which contains  $7\text{SiO}_2$  instead of  $6\text{SiO}_2$  accounts for the high silica. He considers one silicon atom and one ferrous iron or magnesium atom proxies for two aluminum atoms. After arriving at satisfactory end members, the optical properties were correlated with the percentage end member composition. He found that ferric iron decidedly increased the refractive index and birefringence, and that ferrous iron and magnesium decreased the optic angle. Kunitz (8) also found that the iron in micas increased the refractive index and birefringence.

In 1925 Hallimond (5), in working with muscovite found that the  $\text{K}_2\text{O}$  to  $\text{SiO}_2$  ratio remained fairly constant at 1 to 6 and that when this ratio did vary it was due to variations in the  $\text{K}_2\text{O}$ , with the  $\text{SiO}_2$  remaining constant. Many analyses were also found that contained high percentages of water and fluorine. These were accounted for by considering both mutually replaceable, and to be in the lattice structure as  $\text{Al}(\text{OH})_2$  and  $\text{Al}(\text{F})_2$ . He also indicated that ferrous iron and magnesium can replace the aluminum to form phengite, thus giving a system with two end members.

In reviewing the literature there were found several points of dispute that have not been settled, and in order to correlate the optical properties of muscovite accurately with its chemical composition, the members of the muscovite system must be defined. Hundreds of analyses have been published which are widely different and are from material of unknown purity, thus making it extremely difficult to come to a satisfactory conclusion. With this in view, the results reported in this paper were carried out on samples of high quality and were further checked for their purity by methods recently devised.

#### MICAS STUDIED

The micas used in this study were selected from the mineral collections of the Geology Department of the University of Wisconsin and the supply of Ward's Natural Science Establishment. A list of the micas studied, the locality from which they were collected, and the source from which they were obtained are given in Table 1.



TABLE 1. LOCALITY OF OCCURRENCE AND SOURCE OF SUPPLY OF THE MUSCOVITES STUDIED

Muscovite	Locality of Occurrence	Source of Supply
1 M	South Dakota	University of Wisconsin
2 "	Haywood, North Carolina	" " "
3 "	Phenocite Mine, Villa Rio, Piracicoba, Brazil	" " "
4 "	Branchville, Connecticut	" " "
5 "	Kokomo, Colorado	" " "
6 "	Brazil	" " "
7 "	Big Ridge Mica Mine, Haywood, North Carolina	" " "
8 "	Mitchell County, North Carolina	" " "
9 "	India	Wards Nat. Sci. Estb.
10 "	Grafton, New Hampshire	" " " "
11 "	Delaware County, Pennsylvania	" " " "
12 "	Mountville, New Jersey	" " " "
13 "	Auburn, Maine	" " " "
15 "	Haddam Neck, Connecticut	" " " "
16 "	Branchville, Connecticut	" " " "
17 "	Central Australia	" " " "
18 "	Bamle, Norway	" " " "
19 "	Burke Falls, Ontario	" " " "
21 "	Dobrova, Corinthia	" " " "
23 "	Easton, Pennsylvania	" " " "
24 "	Mitchell County, North Carolina	" " " "
25 "	Keystone, South Dakota	" " " "

In a study of this nature, it is extremely important to have samples free of inclusions of other minerals and of unweathered material. To obtain these, samples of muscovite were selected from high grade pegmatite material. Special care was exercised in selecting only that part of the specimen that was of the greatest purity.

#### METHODS OF ANALYSES

The samples of muscovite were ground to pass a 100 mesh sieve and then separated by means of the specific gravity method described by Volk (11) to remove any impurities in the form of inclusions. The material was now ready for chemical analysis. Any free iron oxide remaining was first removed and determined by treating with  $H_2S$  and acidifying according to Drosdoff and Truog (2). The iron thus extracted was subtracted from the total ferric iron to get the amount of ferric iron actually in the silicate molecule. These methods of selection and purification made it possible to obtain total analyses representative of extremely pure muscovite.

All chemical analyses, except those of sodium and potassium, were carried out according to the standard methods outlined by Hillebrand and Lundell (6). The sodium was determined by the sodium zinc uranyl acetate method described by Chapman (1) and the potassium determined by the sodium cobalti-nitrite method according to Volk and Truog (12).

The determinations of the refractive indices were made according to the double variation method of Emmons (4).

### RESULTS AND DISCUSSION

The results from the optical analyses of the muscovites are given in Table 2 and those of the chemical analyses in Table 3.

TABLE 2. OPTICAL DATA OF MUSCOVITES

Muscovite	Refractive indices			Observed optic angle	$\alpha$ - $\gamma$	$\alpha$ - $\beta$	$\beta$ - $\gamma$	F-D Dispersion
	$\alpha$	$\beta$	$\gamma$					
				Degrees				
1 M	1.5943	1.5894	1.5602	44	.0341	.0049	.0292	.0070
2 "	1.6035	1.5994	1.5677	38	.0358	.0041	.0317	.0070
3 "	1.5988	1.5940	1.5637	39.0	.0351	.0048	.0303	.0064
4 "	1.6010	1.5955	1.5649	42.5	.0361	.0055	.0306	.0040
5 "	1.6066	1.6019	1.5592	40	.0474	.0047	.0427	.0057
6 "	1.6034	1.5980	1.5544	41	.0490	.0054	.0436	.0059
7 "	1.6042	1.5995	1.5625	37	.0417	.0047	.0370	.0051
8 "	1.5987	1.5946	1.5577	39	.0410	.0041	.0369	.0058
9 "	1.5951	1.5902	1.5457	39.8	.0494	.0049	.0445	.0087
10 "	1.5985	1.5927	1.5511	41.8	.0474	.0058	.0416	.0066
11 "	1.6113	1.6062	1.5591	37.5	.0522	.0051	.0471	.0072
12 "	1.6029	1.5968	1.5569	43	.0460	.0061	.0399	.0060
13 "	1.5910	1.5855	1.5574	45	.0336	.0055	.0281	.0063
15 "	1.5937	1.5884	1.5587	45	.0350	.0053	.0297	.0067
16 "	1.6026	1.5973	1.5616	41	.0410	.0053	.0357	.0042
17 "	1.5989	1.5945	1.5738	44.3	.0251	.0044	.0207	.0096
18 "	1.6100	1.6043	1.5669	41	.0431	.0057	.0374	.0062
19 "	1.6091	1.6045	1.5711	43.0	.0380	.0046	.0334	.0090
21 "	1.5943	1.5899	1.5512	38	.0431	.0044	.0387	.0069
23 "	1.6114	1.6065	1.5647	37.5	.0467	.0049	.0418	.0071
24 "	1.6110	1.6056	1.5667	38	.0443	.0054	.0389	.0085
25 "	1.5973	1.5914	1.5603	43	.0370	.0059	.0311	.0059

All indices given are  $\pm .0003$ .

TABLE 3. CHEMICAL COMPOSITION OF THE MUSCOVITES

Muscovite	SiO <sub>2</sub> %	Al <sub>2</sub> O <sub>3</sub> %	K <sub>2</sub> O %	Na <sub>2</sub> O %	MgO %	FeO %	Fe <sub>2</sub> O <sub>3</sub> %	CaO %	TiO <sub>2</sub> %	Loss on ig- nition %	Total
1 M	44.25	34.67	10.74	0.54	1.07	1.47	0.00	0.23	trace	6.08	99.05
2 "	44.80	34.50	9.48	1.47	2.40	0.65	0.64	0.00	0.73	5.53	100.20
3 "	45.07	33.95	9.98	1.26	0.51	3.68	0.00	0.17	0.25	5.81	100.68
4 "	42.96	34.24	9.97	1.09	0.63	3.39	0.00	0.09	0.09	6.88	99.34
5 "	44.78	33.80	9.29	1.58	1.10	0.75	1.80	0.34	0.30	6.20	99.94
6 "	43.97	35.58	9.57	1.39	1.82	0.96	0.45	0.00	0.35	6.61	100.70
7 "	42.60	33.60	9.28	1.59	1.57	1.46	0.70	0.80	0.89	7.82	100.31
8 "	42.90	33.21	9.65	1.70	1.37	1.45	0.00	0.00	0.58	9.73	100.59
9 "	42.35	36.50	9.70	1.30	1.60	1.40	0.37	0.50	0.58	6.70	101.00
10 "	44.25	36.98	9.30	1.53	1.50	1.40	0.01	0.31	0.22	5.10	100.65
11 "	44.15	35.35	10.20	1.01	0.89	0.86	2.15	0.28	0.44	5.30	100.65
12 "	43.50	35.41	10.04	1.28	0.80	0.89	0.84	0.31	0.00	6.74	99.81
13 "	44.75	36.51	10.30	0.82	0.41	1.41	0.00	0.00	0.00	5.20	99.40
15 "	44.65	36.63	10.30	0.90	0.61	0.85	0.00	0.20	0.00	5.92	100.06
16 "	43.43	33.92	10.90	0.54	0.75	4.47	0.00	0.00	trace	5.48	99.49
17 "	44.68	34.98	10.35	1.40	0.60	1.04	0.00	0.00	0.39	5.56	99.00
18 "	43.37	33.19	10.17	1.03	1.36	1.00	1.95	0.00	0.33	7.74	100.14
19 "	44.77	33.26	10.58	0.78	1.21	1.34	1.82	0.26	0.18	6.02	100.22
21 "	45.45	34.41	10.44	1.40	3.11	0.40	0.12	0.17	0.31	4.77	100.58
23 "	45.10	33.22	9.98	1.15	0.94	1.21	2.75	0.00	0.25	6.27	100.87
24 "	44.09	33.01	10.30	0.95	1.00	0.66	2.00	0.00	0.10	8.86	100.97
25 "	44.15	34.96	9.81	1.21	1.00	1.32	0.00	0.14	0.11	7.53	100.23

## THE CHEMICAL CLASSIFICATION OF THE MUSCOVITE SYSTEM

The results of the chemical analysis of the muscovites studied have been evaluated according to the methods used by Winchell (15) and Hallimond (5) to determine the likely formulas for the end members of this system. The compositions for Winchell's suggested end members were based upon the amounts of FeO, MgO, Fe<sub>2</sub>O<sub>3</sub>, and K<sub>2</sub>O determined. These were calculated to the following formulas, H<sub>4</sub>K<sub>2</sub>Al<sub>6</sub>Si<sub>6</sub>O<sub>24</sub> (muscovite), H<sub>4</sub>K<sub>2</sub>(Fe''Mg)Al<sub>4</sub>Si<sub>7</sub>O<sub>24</sub> (phengite), and H<sub>4</sub>K<sub>2</sub>Fe<sub>2</sub>'''Al<sub>4</sub>Si<sub>6</sub>O<sub>24</sub>. If these are the correct end members of the muscovite system, the results of the calculations should show no consistent lack or abundance of any one element. Table 4 presents the percentage molecular composition of the muscovites here reported. These results show a consistent lack of silica to fulfill the requirements of these end members. Because of this consistent deficiency of silica, a new formula—H<sub>6</sub>K<sub>2</sub>(Fe or Mg)<sub>2</sub>Al<sub>4</sub>Si<sub>6</sub>O<sub>24</sub>—is suggested for the phengite molecule. In this formula there are two RO groups replacing one R<sub>2</sub>O<sub>3</sub> group, thus eliminating the necessity of



using silicon for this purpose. The water is increased from two to three molecules which corresponds fairly well to the amounts of water found by analysis. Table 4 also presents the percentage composition of the end members, two of which are the same as those used by Winchell, and the third or new member containing  $3\text{H}_2\text{O}$ ,  $2\text{FeO}$  or  $\text{MgO}$ , and  $6\text{SiO}_2$  instead of  $2\text{H}_2\text{O}$ ,  $\text{FeO}$  or  $\text{MgO}$ , and  $7\text{SiO}_2$ . The results show a very good correlation between these members and the chemical composition.

Hallimond (5) computes all of his data on the basis that  $\text{SiO}_2 = 600$ , thus showing the various ratios found in the analyses. Table 5 presents the data calculated according to this system and sets forth some very interesting relations. The  $\text{K}_2\text{O}$  to  $\text{SiO}_2$  ratio remains almost constant at 1 to 6. In only one case out of 22 does the  $\text{RO} + \text{R}_2\text{O}_3$  to  $\text{SiO}_2$  ratio go below 1 to 3 and that one case is 1 to 2.99. This indicates that it is not necessary for silicon to proxy for aluminum and eliminates any necessity of accounting for high silica in any of the muscovites analyzed. By computing the analyses to the two suggested formulas of Hallimond; namely, muscovite,  $\text{K}_2\text{O} \cdot 3\text{R}_2\text{O}_3 \cdot 6\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ , and phengite,  $\text{K}_2\text{O} \cdot \text{RO} \cdot 2\text{R}_2\text{O}_3 \cdot 6\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ , the silica checked within experimental error in 18 cases out of 22, but the aluminum was generally in excess of 1.5 per cent. The aluminum checked within 1.5 per cent excess or deficiency in 18 out of 22 cases when  $2\text{RO}$  were substituted for one  $\text{R}_2\text{O}_3$  as is suggested for the new phengite molecule.

TABLE 4. THE MOLECULAR COMPOSITION OF MUSCOVITE BASED ON THE PERCENTAGE OF POTASSIUM MUSCOVITE, PHENGITE, AND FERRIC IRON MUSCOVITE MOLECULES

Muscovite	Per cent molecular composition						Per cent of SiO <sub>2</sub> and Al <sub>2</sub> O <sub>3</sub> not required or lacking to fulfill the formulas by			
	by Winchell's end members			by using new phengite formula			Winchell		New phengite	
	H <sub>4</sub> K <sub>2</sub> Al <sub>6</sub> Si <sub>6</sub> O <sub>24</sub>		H <sub>4</sub> K <sub>2</sub> (Fe, Mg)- Al <sub>4</sub> Si <sub>7</sub> O <sub>24</sub> (phengite)	H <sub>4</sub> K <sub>2</sub> Fe <sub>2</sub> '''- Al <sub>4</sub> Si <sub>6</sub> O <sub>24</sub>	H <sub>4</sub> K <sub>2</sub> Al <sub>6</sub> Si <sub>6</sub> O <sub>24</sub>	H <sub>6</sub> K <sub>3</sub> - (Fe''Mg) <sub>2</sub> - Al <sub>4</sub> Si <sub>6</sub> O <sub>24</sub>	H <sub>4</sub> K <sub>2</sub> Fe <sub>2</sub> '''- Al <sub>4</sub> Si <sub>6</sub> O <sub>24</sub>		SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>
	H <sub>4</sub> K <sub>2</sub> Al <sub>6</sub> Si <sub>6</sub> O <sub>24</sub>	H <sub>4</sub> K <sub>2</sub> (Fe, Mg)- Al <sub>4</sub> Si <sub>7</sub> O <sub>24</sub> (phengite)	H <sub>4</sub> K <sub>2</sub> Fe <sub>2</sub> '''- Al <sub>4</sub> Si <sub>6</sub> O <sub>24</sub>	H <sub>4</sub> K <sub>2</sub> Al <sub>6</sub> Si <sub>6</sub> O <sub>24</sub>	H <sub>6</sub> K <sub>3</sub> - (Fe''Mg) <sub>2</sub> - Al <sub>4</sub> Si <sub>6</sub> O <sub>24</sub>	H <sub>4</sub> K <sub>2</sub> Fe <sub>2</sub> '''- Al <sub>4</sub> Si <sub>6</sub> O <sub>24</sub>	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>		
1 M	63.2	36.8	0	80.5	19.5	0	-2.7	+2.0	0	-0.4
2 "	43.3	55.5	3.2	69.8	27.0	3.2	-3.1	+3.7	+0.8	+0.2
3 "	48.5	51.5	0	74.4	25.6	0	-3.3	+2.5	+0.4	-0.8
4 "	48.0	52.0	0	74.0	26.0	0	-4.1	+3.6	-0.3	+0.5
5 "	61.5	30.4	9.5	75.5	15.4	9.1	-1.7	+1.0	+0.4	-0.6
6 "	50.8	47.0	2.2	74.4	23.4	2.2	-4.0	+3.7	-0.5	+0.7
7 "	48.9	47.5	3.6	72.6	23.8	3.6	-5.0	+2.0	-1.4	-0.9
8 "	58.2	41.8	0	76.5	23.5	0	-7.3	-0.8	-3.9	-4.0
9 "	50.2	48.0	1.8	74.0	24.2	1.8	-5.4	+4.6	-2.0	+1.5
10 "	55.0	45.0	0	77.5	22.5	0	-3.6	+4.8	0	+2.1
11 "	61.7	27.4	10.9	75.4	13.7	10.9	-2.3	+2.3	-0.2	+0.5
12 "	70.0	25.6	4.4	82.0	13.6	4.4	-7.0	+0.4	-1.8	-1.1
13 "	75.0	25.0	0	87.5	12.5	0	-1.2	+2.1	+0.5	+0.5
15 "	78.2	21.8	0	89.0	11.0	0	-1.2	+1.7	+0.2	+0.2
16 "	35.0	65.0	0	70.0	30.0	0	-9.0	+4.2	-1.2	0
17 "	78.0	22.0	0	89.0	11.0	0	-4.4	-2.7	-2.7	-4.2
18 "	52.0	38.2	9.8	71.0	19.2	9.8	-3.9	+1.3	-1.1	0
19 "	51.5	39.0	9.5	71.0	19.5	9.5	-2.8	+1.2	0	-1.3
21 "	38.0	62.0	0	69.0	31.0	0	-7.2	+2.2	-2.2	-2.0
23 "	53.6	32.4	14.0	69.8	16.2	14.0	-2.0	+1.0	-1.0	+0.4
24 "	50.5	39.5	10.0	70.2	19.8	10.0	-3.6	+1.3	-1.2	-0.7
25 "	65.0	35.0	0	82.4	17.6	0	-2.7	+1.6	-0.1	-0.5

TABLE 5. THE MOLECULAR EQUIVALENTS OF THE OXIDES, OF THE MUSCOVITES STUDIED, COMPUTED ON THE BASIS OF  $\text{SiO}_2 + \text{TiO}_2 = 600$ 

No.	$\text{Al}_2\text{O}_3$	$\text{Fe}_2\text{O}_3$	$\text{FeO}$	$\text{MgO}$	$\text{RO} + \text{R}_2\text{O}_3$	$\text{R}_2\text{O}$	$\text{H}_2\text{O}$
1	277	—	17	21	315	100	276
2	267	3.2	7.5	45	323	98	243
3	266	—	41	10	317	99	257
4	280	—	39	13	332	101	320
5	266	9	8.3	21.8	305	99	275
6	284	2.3	11.0	36.7	334	101	300
7	275	—	16.8	31.0	323	103	370
8	270	—	15.8	30	316	108	448
9	301	1.9	16.4	32.2	351	105	313
10	295	—	15.9	29.3	340	100	230
11	280	11.0	9.7	17.8	318	101	248
12	288	4.4	10.3	16.6	319	105	310
13	291	—	16.6	8.5	316	99	235
15	291	—	9.6	12.0	313	99	264
16	276	—	51.5	15.3	337	103	252
17	274	—	11.6	11.6	299	105	247
18	269	10.1	11.4	27.8	318	103	355
19	261	9.1	15.0	24.0	309	100	267
21	267	—	4.3	61.0	332	105	210
23	269	13.8	13.5	18.5	315	99	276
24	265	10.2	7.5	32.9	316	102	400
25	280	—	15.1	20.2	315	101	341

The new formula for the phengite member presented in this paper appears to be in full accord with the chemical composition of the muscovites studied. A reduction of the silica from  $7\text{SiO}_2$ , as given by Winchell, to  $6\text{SiO}_2$ , as used in the new formula, accounts for the deficiency of silica noted when  $7\text{SiO}_2$  was used. This change in silica content leaves the phengite with only 23 oxygens and in order to increase the oxygen content to 24 the water has been changed from two to three molecules. There is sufficient water recorded in the analyses to account for this change in water. It is not uncommon to find many muscovites with high water content and as suggested by Hallimond, it may be accounted for in the crystal lattice in groups such as  $\text{Al}(\text{OH})_2$  and  $\text{AlO}$ , or an interchange between them. There is a possibility that the extra hydroxyl radical may be combined with the ferrous iron as in  $\text{Fe}(\text{OH})_2$ . There is another change in the new phengite molecule formula which is also substantiated by the group of muscovites studied in this work. This change is the replacement of  $1\text{R}_2\text{O}_3$  group by  $2\text{RO}$  groups instead of an exchange of  $1\text{RO}$  for  $1\text{R}_2\text{O}_3$ , as suggested in the old formula. Thus



we have built up a new formula for the phengite molecule which is not radically different in form from the other two members of the muscovite system and which coincides satisfactorily with the chemical composition of the muscovites reported in this paper.

#### RELATION OF OPTICAL PROPERTIES TO CHEMICAL COMPOSITION

In determining the relation of the optical properties to the chemical composition of muscovite, the end members selected are those suggested in an earlier part of this paper; namely, potassium muscovite

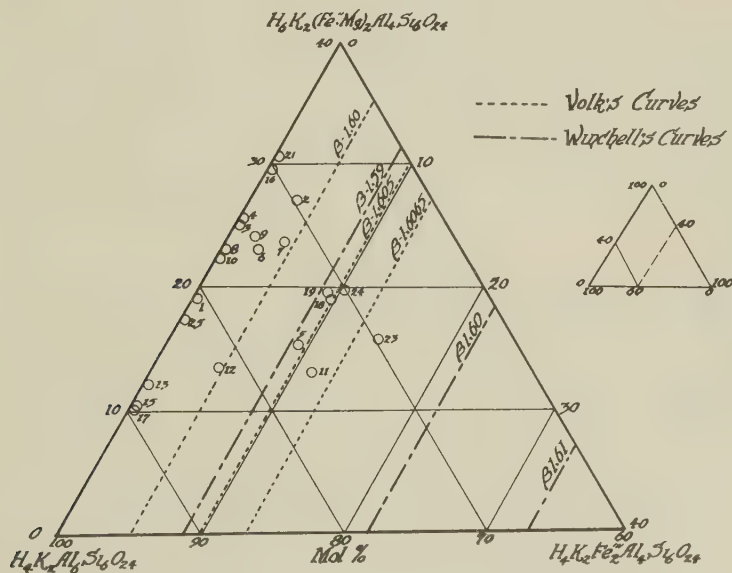


FIG. 1. Variations in the composition and refractive index in the muscovite system.

( $H_4K_2Al_6Si_6O_{24}$ ), phengite ( $H_6K_2(Fe''Mg)_2Al_4Si_6O_{24}$ ), and ferric iron muscovite ( $H_4K_2Fe_2'''Al_4Si_6O_{24}$ ). The end member compositions were then plotted on a three component diagram as shown in Fig. 1. This is the same type of diagram used by Winchell (14), and the lines drawn through it indicate the values of  $\beta$  determined in this study and those reported by Winchell (14). The results show that the values of  $\beta$  increase with increasing amounts of the ferric iron muscovite, which is in accord with the findings of Winchell.

The effect of the phengite content of the muscovite system on the

optic angle is shown in Fig. 2. When the phengite increases, the optic angle decreases, but when there are considerable amounts of ferric iron present along with small amounts of phengite, the same effect is registered on the optic angle. To further check this effect of ferric iron, some analyses of muscovites by Jakob (7), Smirnoff (9) and Eckermann (3) were plotted on the same graph. These show the same effect.

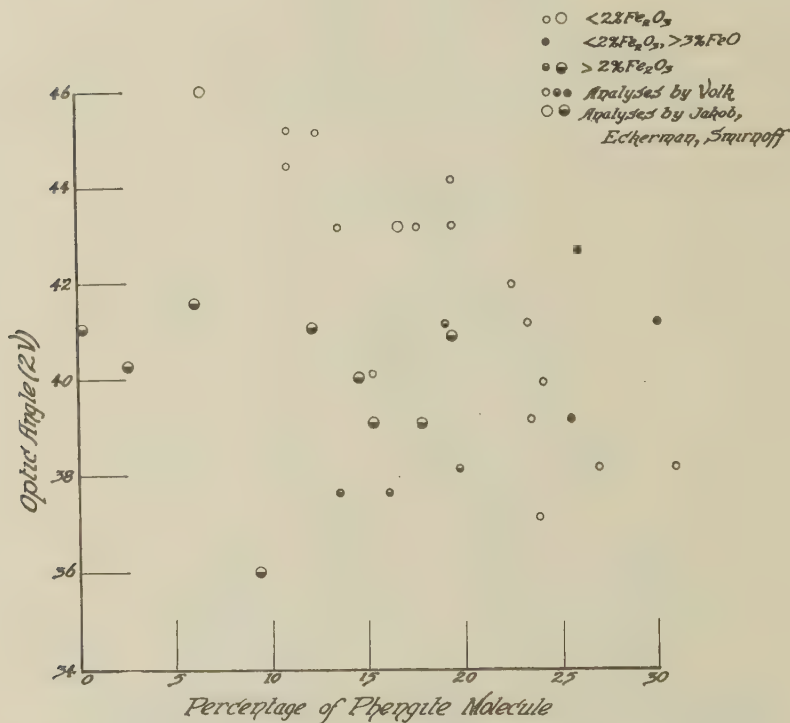


FIG. 2. The effect of the phengite molecule on the optic angle.

A study of dispersion and birefringence did not show any correlation with the chemical composition, but this may be due to the limited number of samples used in this investigation.

In order that the true relations may be expressed between the chemical composition and the optical properties of a mineral, it is necessary to use results from materials of high purity. The formulas expressing the actual form of the minerals present must also be used.

The relations expressed in the diagrams between the optical properties

and the chemical compositions are only general, and are not so accurately established as is desired. This, however, is because there was an insufficient number of samples used and the range was incomplete even though the extremes in optical properties were covered. The differences between the values of  $\beta$  as given by Winchell and those reported here may be explained as being due to the use of purer samples in the latter case, which was made possible by the use of improved methods of purification. These methods removed considerable amounts of free ferric iron which has no effect on the refractive index. After the removal of the free ferric iron any effect on the refractive index by iron would have to be caused by that which is in the silicate molecule.

The effectiveness of the phengite molecule in reducing the optic angle is much greater than that recorded by Winchell. This is due to the nature of the new phengite molecule which has 2RO groups in place of 1RO group and thus reduces the phengite one-half in the muscovite system. It appears that muscovite specimens of high quality must be used if more accurate relations between the optical properties and chemical composition are to be established.

#### SUMMARY

The purpose of this investigation was to obtain more information on the optical properties and chemical classification of the muscovite system. Twenty-two samples of muscovite, first purified by means of heavy liquids, and then the remaining free iron oxide removed by treating with  $H_2S$  and acidifying, were used in this study. These muscovite samples were then analyzed chemically and their optical constants determined. A summary of the results follows:

The chemical formulas for the members of the muscovite system which correspond most accurately with the chemical composition are: potassium muscovite ( $H_4K_2Al_6Si_6O_{24}$ ), phengite ( $H_6K_2(Fe,Mg)_2Al_4Si_6O_{24}$ ), and ferric iron muscovite ( $H_4K_2Fe_2'''Al_4Si_6O_{24}$ ). It was necessary to adopt this new formula for phengite in order to get satisfactory correlation with the results of chemical analyses.

When the ferric iron muscovite content of the system increases, the refractive index rises.

The optic angle decreases with an increase in the amount of phengite. The optic angle also decreases when small amounts of phengite are present with large amounts of ferric iron muscovite.

No correlation has been established between the birefringence or dispersion and the chemical composition of the muscovites analyzed.



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## OCCURRENCE OF CHRYSOBERYL NEAR GOLDEN, COLORADO

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In March, 1938, chrysoberyl of unusual interest was discovered by R. V. Gaines in a small granite pegmatite dike near Drew Hill, about ten miles from Golden, Colorado. The mineral specimens first obtained from the deposit were identified as chrysoberyl by the senior author, and the identification was subsequently checked by qualitative analyses made at the Experimental Plant of the Colorado School of Mines.

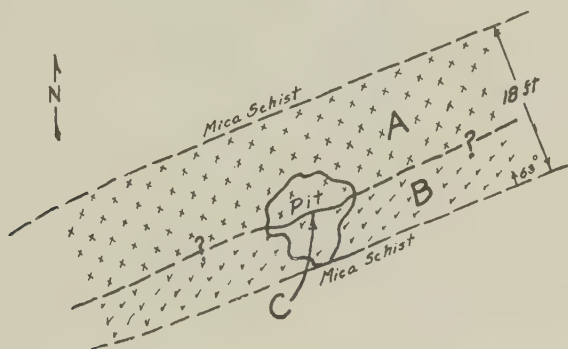


FIG. 1. Sketch of chrysoberyl-bearing dike. A. Massive orthoclase and perthite. B. Coarse granite pegmatite. C. Contact of parts A and B near which chrysoberyl occurs with massive quartz and quartz-muscovite aggregates.

The presence of a shallow pit, in and around which the first specimens of chrysoberyl were found, indicated that the dike had been prospected for feldspar. Had it not been for this early prospecting, the chrysoberyl herein described probably would have remained undiscovered. Recently, the writers deepened the prospect pit by blasting and obtained some additional specimens. Inasmuch as the crystals and crystalline masses of chrysoberyl from this deposit are exceptionally large, the writers believe that a description of them and of the dike in which they occur is well warranted.

The dike containing the chrysoberyl is rather distinctly divided into two parts as illustrated in Fig. 1. One part consists of coarse granite pegmatite in which orthoclase, quartz, muscovite and tourmaline are distributed in a relatively uniform manner. In contrast to this, the other part consists essentially of massive orthoclase and perthite. Chrysoberyl

occurs along the contact of the two parts of the dike, near segregated masses of quartz and muscovite. Some chrysoberyl crystals are practically enclosed in quartz, but extend slightly into the massive feldspar; others are virtually enclosed in the feldspar but extend slightly into massive quartz; and some small crystals are included in aggregates of quartz and muscovite. The majority of the twinned chrysoberyl crystals are closely associated with massive quartz; whereas, most of the single crystals are included in feldspar or in the quartz-muscovite aggregates.

All of the chrysoberyl thus far obtained from the deposit has a relatively uniform olive-green color. Its average specific gravity, determined

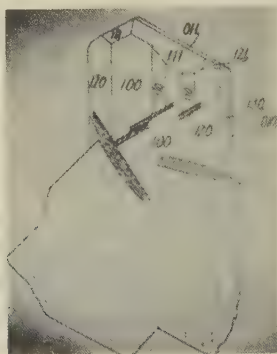


FIG. 2. Chrysoberyl.—Colorado.

from small particles obtained by screening dump material, is 3.648. Cleavage parallel to the brachypinacoid is good, but is poor or lacking entirely in other directions. All of the cleavage faces have a brilliant luster.

The composition of the chrysoberyl, as determined at the Experimental Plant of the Colorado School of Mines, is as follows:

BeO	19.15 per cent
Al <sub>2</sub> O <sub>3</sub>	76.34
FeO	3.60
TiO <sub>2</sub>	0.55
SiO <sub>2</sub>	tr.
Mn	tr.
Cr	None
Loss on ignition	0.30
Acid sol. iron	tr.

*Analyst:* W. P. Schoder

Only the largest and best developed specimens of chrysoberyl have been selected for illustrations and detailed descriptions. Figure 2 shows



the various forms identified on one of the well-terminated small crystals.

The specimen illustrated in Fig. 3 is the second largest of the single chrysoberyl crystals yet found in the deposit. It is 1.7 cm. thick, 4.0 cm. wide, and 9.2 cm. long. The faces of the crystal include a well-developed macropinacoid, a very narrow brachypinacoid, a good pyramid, a narrow brachydome, and a poorly developed prism. Some striations are present on the macropinacoid faces. Associated with the crystal are muscovite, orthoclase, and massive chrysoberyl. Muscovite is present



FIG. 3. Chrysoberyl. Fragment at left broken from surface marked A.  
Weight of group illustrated, 941 grams.

as small brilliant flakes on the crystal faces and as large flakes (6.2 cm. average diameter) between the crystal and the orthoclase. Flakes of similar size occur also between the crystal and the adjacent chrysoberyl masses. It was necessary to photograph the specimen in two parts, because the large crystalline mass of chrysoberyl, when attached to the surface "A" in the Fig. 3, obscured the termination of the crystal.

The largest twinned chrysoberyl specimen found in the deposit is illustrated in Fig. 4. It is 2.54 cm. thick, 14 cm. wide, and 12 cm. long. Attached to the crystal, but not evident in the figure, are some gray quartz and a tabular chrysoberyl mass 1.7 cm. in thickness. Small, brilliant muscovite flakes occur on the crystal and cleavage faces, and also between the chrysoberyl and massive quartz. Minute crystals of tourma-

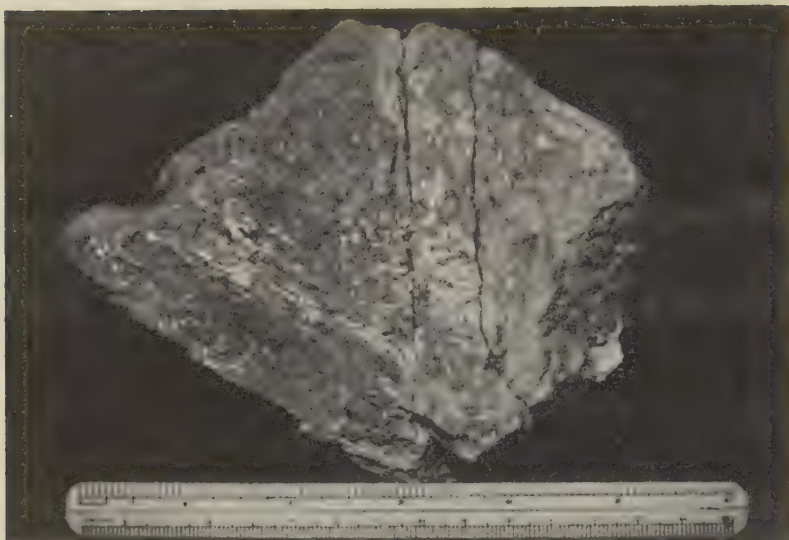


FIG. 4. Twinned chrysoberyl. Weight 1302 grams.]

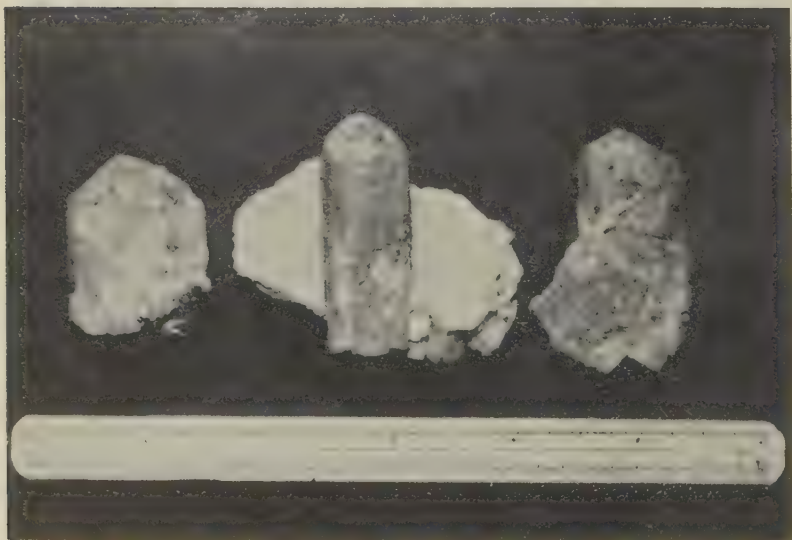


FIG. 5. Chrysoberyl crystals from Colorado.

line, intergrown with muscovite, form a thin film on some of the cleavage faces. Figure 5 illustrates three well developed chrysoberyl crystals.

The quantity of chrysoberyl in the deposit described is extremely problematical. A careful study has been made of the dike along its entire outcrop, but all of the specimens thus far collected (approximately 50 kilograms) have been found in or near the prospect pit. Distribution of the chrysoberyl in the dike undoubtedly is very erratic because its occurrence, as observed, indicates that it will be found only where the texture of the dike is extremely variable, and where quartz or quartz-muscovite aggregates are present as large masses.

## NOTES AND NEWS

### THE ANALYSIS OF TWO SAMPLES OF PITCHBLLENDE ORE FROM GREAT BEAR LAKE, CANADA

JOHN PUTNAM MARBLE<sup>1</sup>

In connection with the coöperative program of scientific study on the pitchblende ore from Great Bear Lake, complete analyses have been made of the two samples from which have been derived the material used in all previously described experiments. As these analyses have been requested by several workers, it was thought possibly worth while to put them on record.

In both cases the material came from the workings of the Eldorado Gold Mines, Ltd., at LaBine Point, Great Bear Lake, N.W.T., Canada. Sample 1 came from Pit No. 1, Vein No. 1, from near the surface in the early days of the workings. Sample 2 came from the 800-foot section of No. 2 Vein, at more than 100 feet below ground. Both samples were supplied by H. S. Spence of the Canadian Department of Mines, from material personally obtained by him at the mines. For his kindness we are deeply grateful.

Sample 1 is the identical material used by Lindgren (1932), Newhouse (1932), von Grosse (1933), Piggot (1933), Aston (1933), Marble (1934), Marble (1936), and Nier (1939) in various studies. Sample 2 is the material described by Marble (1937), and on which further work is now in progress.

It should be made clear that these are analyses of the ore samples as received, and do not represent the pure mineral species. A considerable amount of silica, some sulfides, and a few small fragments of country rock are present. The low density is to be accounted for by the silica and silicates. The silver reported is present as metallic silver, which accompanies the pitchblende. The percentages of lead, uranium, and thorium are the mean of the previously published values. Nearly all the other figures are the mean of two or more closely agreeing determinations.

The courtesy of the Director of the U. S. Geological Survey and of the Assistant Secretary of the U. S. National Museum for the use of laboratory facilities is gratefully acknowledged.

<sup>1</sup> Committee on Measurement of Geologic Time, Division of Geology and Geography, National Research Council, Washington, D. C.



## PITCHBLEND ORE FROM GREAT BEAR LAKE, N. W. T., CANADA

	Sample 1	Sample 2
U <sub>3</sub> O <sub>8</sub>	61.56%	34.66%
Pb	10.51	5.88
ThO <sub>2</sub>	<0.01	<0.01
SiO <sub>2</sub>	15.26	44.07
CaO	1.44	1.90
MgO	0.26	0.87
ZrO <sub>2</sub>	0.00	n.d.
CuO	1.11	1.21
Ag	0.01	0.04
MnO	<0.01	0.00
Ce <sub>2</sub> O <sub>3</sub>	0.18	0.58
Yt <sub>2</sub> O <sub>3</sub> , etc.	0.53	0.35
La <sub>2</sub> O <sub>3</sub> , etc.	0.39	0.31
Other rare earths	0.31	0.00
Fe <sub>2</sub> O <sub>3</sub>	1.52	6.35
Al <sub>2</sub> O <sub>3</sub>	0.27	0.45
TiO <sub>2</sub>	0.05	tr.
BaO	0.01	0.01
K <sub>2</sub> O+Na <sub>2</sub> O	1.36	tr.
V <sub>2</sub> O <sub>5</sub> +MoO <sub>3</sub>	1.14	0.32
NiO+CoO	2.42	0.62
S	0.75	1.32
H <sub>2</sub> O (-110°)	0.66	0.80
H <sub>2</sub> O (+110°)	0.87	1.59
Ignition loss	gain	gain
	100.63	101.34
Less O $\approx$ S	0.38	0.66
Total	100.25%	100.68%
Density = 5.95		Density = 3.70

J. P. MARBLE, *Analyst*

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VESUVIANITE AND FLUORESCENT APATITE FROM CENTER STRAFFORD,  
NEW HAMPSHIRE

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*University of New Hampshire, Durham, N. H.*

## INTRODUCTION

During the excavation of a small gravel pit one mile east of the village of Center Strafford, N. H., a water-worn ledge was exposed in which vesuvianite is present in long, thin, lens-like masses three or four inches wide and ten to fifteen feet in length. A small lens-shaped mass of muscovite mica and fluorescent apatite in this ledge is also worthy of description. The formation in which the vesuvianite and associated minerals occur is, according to F. J. Katz (1917), the Rindgemere formation of Carboniferous (Pennsylvanian ?) age, consisting of slates, phyllites and schists with occasional interbedded argillaceous quartzites and limestones. At this locality the formation is primarily quartzitic with thin beds of very impure limestone. A granitic body outcrops about one hundred feet west of the vesuvianite deposit and is considered to be of post-Carboniferous age.

The writer wishes to express his appreciation to Mr. T. R. Meyers of the University of New Hampshire and to Mr. Wallace E. Richmond of Harvard University for their advice and criticism.

## VESUVIANITE

The mineral occurs in radiating columnar masses locally replaced by orthoclase, and is brown in color. In an occasional pocket one or more distinct prismatic faces,  $m\{110\}$ , are usually present. Pyramidal faces are rare, with  $p\{111\}$  occasionally present. No completely formed crystals were found. Most of the crystalline masses are slightly transparent and have a resinous luster. Striations are present on the prism faces and parallel the direction of the  $c$ -axis. The indices of refraction determined by the immersion method with white light are:  $\omega=1.710$ ,  $\epsilon=1.702$ . Birefringence is 0.008.

Locally the vesuvianite is replaced by orthoclase (adularia) which forms subhedral crystals that range in size from one to fifteen millimeters in length. Small  $c\{001\}$  faces and rather long  $m\{110\}$  faces are recognizable on some of the crystals. All crystals show a distinct basal cleavage and the majority have a dull luster due to hydrothermal alteration. Occasionally a crystal has escaped this alteration and displays a brilliant vitreous luster. The mineral is biaxial negative,  $2V=\text{about } 65^\circ$ , and the indices of refraction are:  $\alpha=1.519$ ,  $\beta=1.525$ , and  $\gamma=1.527$ ;  $B.=0.008$ , dispersion is weak and  $Z=b$ -axis.

## FLUORAPATITE

Of special interest is a small lens-shaped mass of fluorapatite and muscovite mica that lies about ten feet below the vesuvianite lenses and is parallel to them. The fluorapatite occurs in short prismatic crystals replacing the muscovite and ranges from one to five millimeters in width and from three to twelve millimeters in length. The mineral is pale blue to colorless, with a vitreous luster, and is translucent. Under the mercury vapor lamp the mineral displays a strong light orange color. The indices of refraction are:  $\omega = 1.632$  and  $\epsilon = 1.629$ . Birefringence is 0.003.

## SUMMARY

From the study of four thin sections, vesuvianite was found to be confined to definite layers. The original calcareous beds have been almost entirely replaced by vesuvianite, orthoclase, epidote, diopside and interstitial calcite. In the quartzitic beds hornblende, biotite, and sphene are present. The vesuvianite and the associated minerals, together with the granitic body close by, suggests a contact metamorphic replacement of a calcareous sandstone.

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## WORLD DISTRIBUTION OF SERPENTINIZED PERIDOTITES AND ITS GEOLOGIC SIGNIFICANCE\*

HARRY H. HESS,

*Princeton University, Princeton, New Jersey.*

The serpentinization of peridotites is considered to be caused by water present in the magma at the time of crystallization. Alteration of peridotites forms biotite, actinolite, chlorite, talc, carbonates, and is considered to be the result of later hydrothermal solutions commonly from granitic intrusions.

The serpentinized peridotites are regarded as products of an ultramafic magma having approximately the composition of the mineral serpentine. Certain other peridotites are undoubtedly formed by crystallization differentiation from basaltic magmas. (Kimberlites, biotite pyroxenites, etc., form a third group of ultramafic igneous rocks which, together with those from basaltic magmas, were not considered in the discussion.)

\* Abstract of a talk given before the New York Mineralogical Club, New York, N. Y.

Serpentinized peridotites of the type under discussion are related to island-arc structures and lie close to the belt of negative gravity anomalies found in the East and West Indies as well as the Marianne arc of the Pacific. They are also found as long narrow belts along the cores of mountain systems or the roots of old eroded mountain systems, which also presumably went through an island-arc stage. In the West Indies it was found that they were intruded during the first great deformation of the present arc, but did not accompany later deformations. This type of peridotite is never found anywhere but in island arcs or mountain belts as mentioned above.

The serpentine belts of the world were plotted on maps of the continents. Six ages of serpentine intrusion have been noted: Archaean, mid Proterozoic, late Ordovician, Carboniferous, late Jurassic or Lower Cretaceous, and Middle Eocene. Belts of serpentines of each age have a worldwide distribution, and can often be traced uninterruptedly for thousands of miles.

Inasmuch as the serpentine belts lie along the axis of the zones of major deformation of the earth's crust, they perhaps may be used by geologists to unravel the difficult problem of tracing the course of and dating ancient mountain systems. On most continents they show a rudely concentric arrangement, with the oldest at the center, suggesting the building up of the continents from a small central nucleus with the development of successive island arcs around it and the successive fusion of each deformed zone onto the core to increase its size.

## BOOK REVIEW

ANGEWANDTE KRISTALLSTRUCTURLEHRE. E. BRANDENBERGER. 208+VII pages, 88 figures. Gebrüder Borntraeger, Berlin; 1938. Price R.M. 12 (paper); R.M. 13.50 (cloth).

This volume is intended to serve as a guide in the use of the International Tables for the Determination of Crystal Structure. The various x-ray methods and actual procedures of structure determination are not considered, but rather the geometrical and crystallographic background, including symmetry, translations, point groups, space groups, and use of interference data. For a person beginning work in the field of crystal structure, and who has a good command of German, this book would be very helpful. The advanced worker in this field will find much of an elementary nature, but the subject is thoroughly covered and well presented, and brings together in one volume material which is rather widely scattered in the literature.

L. S. RAMSDELL



## PROCEEDINGS OF SOCIETIES

### MINERALOGICAL SOCIETY OF GREAT BRITAIN AND IRELAND

January 26th, 1939.

Dr. L. J. Spencer, President, in the chair.

The following were exhibited: a slide rule designed to facilitate geological calculations by Dr. A. T. J. Dollar; native silver from Kongsberg, Norge, by Prof. H. F. Harwood; axinite, apatite and prehnite from Graubünden, Switzerland, by Mr. F. N. Ashcroft and a flawless, step-cut danburite weighing 138.61 carats, by Mr. C. W. Mathews.

The following papers were read:—

(1) *An x-ray examination of some potash-soda-feldspars.* By MR. S. H. CHAO, MR. D. L. SMARE, and DR. W. H. TAYLOR.

The paper presents the results of an examination by x-ray methods of a series of microperthitic potash-soda-feldspars of varying composition, in the normal state and after homogenization by prolonged heating at high temperatures. The crystal of the natural microperthite contains two closely related structures, one (containing the potash-feldspar) being monoclinic, the other (containing most of the soda-feldspar) being triclinic but different from ordinary albite. The crystal of the homogenized specimen contains only one single structure. The cell dimensions of both normal and treated specimens depend in a rather complicated way upon the amount of soda-feldspar present.

(2) *Some minerals from the leucite-rich rocks of the West Kimberley area, Western Australia.* By DR. R. T. PRIDER.

Three minerals have been described, with chemical and optical data, from these leucite-lamproites. Magnophorite is the name suggested for a new amphibole which shows affinities with katophorite but which differs from known amphiboles in having  $K_2O > Na_2O$  combined with high  $TiO_2$  and  $MgO$  and low  $Al_2O_3$  and iron. Wadeite is a new potassium-zirconium silicate which occurs sparingly in colorless hexagonal prisms. The third mineral is titaniferous phlogopite.

(3) *The composition of francolite.* By MR. E. B. SANDELL, DR. M. H. HEY, and MR. D. MCCONNELL.

A chemical analysis, and optical and x-ray examination have been made of a specimen of francolite from the original occurrence; francolite is shown to be a fluor-carbonate apatite with some hydroxyl. The analysis indicates that carbon enters the lattice positions of calcium and phosphorus.

(4) *An eyepiece micro-planimeter.* By MR. H. B. S. COOKE (Communicated by DR. F. COLES PHILLIPS).

A photographically reproduced micrometer scale is fitted in the ocular of the microscope in place of the usual linear scale. From a zero point at the centre of the field of view, distances are marked proportional to the radii of concentric circles of regularly increasing area. Thus for a circular object centred on the stage the scale reading of the circumference would at once give the area. For an object of irregular outline the area is integrated as the sum of a number of circular segments, successive readings being taken at regular intervals of rotation of the stage. The device is cheap, yields accurate results quickly, and does not strain the eyes.

(5) *A new occurrence of bavenite.* By DR. G. F. CLARINGBULL.

X-ray and spectrographic data show that a white fibrous mineral from Muotta Nera, Graubünden, Switzerland, is bavenite.

(6) *The Huckitta meteorite, Central Australia.* By DR. C. T. MADIGAN, with chemical analyses by DR. A. R. ALDERMAN.

A large pallasite was found in 1937 near Huckitta station, 135 miles N.E. of Alice Springs. The mass of 1415 kg. (3112 lb.) and 927 kg. of weathered iron-shale have been transported to Adelaide. Slices, one nearly four feet long, show fragments of olivine embedded in a ground of granular kamacite, with some plessite areas and little troilite and schreibersite. Olivine, with  $\text{MgO}:\text{FeO}=6.8$ , forms 58% by volume (40.1% by weight), and the metal has a ratio  $\text{Fe}:\text{Ni}=9.95$ . The Alice Springs pallasite, described in 1932, is no doubt a transported fragment of this mass.

(7) *Sapphirine crystals from Blinkwater, Transvaal*. By PROFESSOR E. D. MOUNTAIN.

Crystals up to 2 inches across are tabular parallel to the clinopinacoid and show a characteristic habit with interfacial angles measurable only to the nearest degree. The elements  $a:b:c=0.6889:1:1.4056$ ,  $\beta=68^\circ 33'$ , based on previous work, are consistent with the results obtained. Optic axial plane parallel to (010) with  $\gamma:c=6^\circ$  in the obtuse axial angle. A chemical analysis agrees approximately with the accepted formula.

G. F. CLARINGBULL, *General Secretary*

## NEW YORK MINERALOGICAL CLUB, INC.,

The American Museum of Natural History,  
New York City

*Meeting of February 15, 1939.*

The meeting was called to order by first Vice-President Lee at 8:10 P.M., with about 45 members and guests present. After the election of a Nominating Committee for the officers of the next year, the speaker, Mr. James F. Morton, was introduced.

Mr. Morton addressed the Club upon "Zeolite Collecting in Nova Scotia." He described the country as being wild and rugged, an ideal resort country. Nova Scotia is famous for the zeolites which are to be picked up along the shore at the foot of the cliffs during the time the tide is out. Cape Blomidon and Cape Split, on the south side of the Minas Basin and Wasson's Bluff, Partridge Island and Cape Sharp on the north side, were described, and the minerals distinctive of each region were mentioned and shown. Mr. Morton called attention especially to the tides, and cautioned the members against letting their enthusiasm get the better of their judgment. He said it was best to start just after the tide was full, as soon as a little beach was exposed and work for four hours in safety, collecting the zeolites along the shore, like so many shells on the beach. The winter storms guarantee a perpetually renewed supply and one can be certain of finding some good specimens.

F. H. POUGH, *Secretary*

## NEW MINERAL NAMES

### Weberite

RICHARD BØGVAD: Weberite, a new mineral from Ivigtut. *Meddelelser om Grønland*, 119, No. 7, 1-11 (1938), 2 figs., 1 plate.

NAME: In honor of Theobald Weber, who was active in the early development of the Greenland cryolite deposits.

CHEMICAL PROPERTIES: A sodium, magnesium, aluminum fluoride:  $\text{Na}_2\text{MgAlF}_7$ . Analysis (by H. Buchwald): Al 11.65; Fe 0.37; Ca 0.08; Mg 10.43; Na 19.08; K 1.19; F 57.58, remainder 0.16. Sum 100.54. Slightly soluble in water (0.02 gm./100 c.c.  $\text{H}_2\text{O}$ ); soluble in an aqueous solution of  $\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$ . B.B. turns white and swells up, but does not fuse to a drop. After ignition shows an alkaline reaction and with cobalt nitrate an Al re-



action. On heating in a closed tube yields a small quantity of white solid sublimate, gives off acid vapors and corrodes the glass.

CRYSTALLOGRAPHICAL PROPERTIES: No crystals found. Probably monoclinic.

PHYSICAL AND OPTICAL PROPERTIES: Color light gray, streak white. Translucent. Luster vitreous.  $G.=2.96$ ,  $H.=3.5$ . Fracture uneven.

Biaxial, positive.  $2V=83^{\circ}\pm 3^{\circ}$ .  $\alpha=1.346$ ,  $\beta=1.348$ ,  $\gamma=1.350$ .  $\gamma-\alpha=0.004$ . Two conspicuous cleavages perpendicular to the axial plane making angles of  $33^{\circ}$  and  $39^{\circ}$  with the  $\beta-\gamma$  plane, a poor cleavage parallel to the optic axial plane.

OCCURRENCE: Sporadically present in the cryolite of Ivigtut, Greenland. Often surrounded by fluorite and associated with topaz, quartz, feldspar, siderite, other fluorides, etc.

W. F. FOSHAG

### Khoharite

LEWIS LEIGH FERMOR: On khoharite, a new garnet, and on the nomenclature of garnets. *Rec. Geol. Surv. India*, **73**, pt. 1, 145-156 (1938), 1 fig.

A hypothetical garnet molecule,  $3MgO \cdot Fe_2O_3 \cdot 3SiO_2$ , believed to be present in a garnet from Jagersfontein Mine, S. Africa. Analysis (by Percy A. Wagner):  $SiO_2$  40.79,  $Al_2O_3$  12.81,  $Fe_2O_3$  14.35,  $Cr_2O_3$  1.03,  $FeO$  7.39,  $CaO$  5.46,  $MgO$  17.89; sum 99.72. The calculated content of  $3MgO \cdot Fe_2O_3 \cdot 3SiO_2$  equals 10.36 per cent.

The name, khoharite, is derived from the Khohar meteorite, since Fermor believes that meteoric chondrules, like those of the Khohar meteorite have an origin from a garnet,  $3(Mg, Fe)O \cdot Fe_2O_3 \cdot 3SiO_2$ . The molecule  $3FeO \cdot Fe_2O_3 \cdot 3SiO_2$  he has already named skiagite (*Cf. Am. Mineral.*, **13**, 33, 1928).

The nomenclature of the garnets is further expanded to include gralmandite (grossularite-andradite). Where the molecular percentage is less than 10% the garnet names may be modified by chemical prefixes: calc-pyralmandite, ferro-spessartite, magnesia-gralmandite, manganese-gralmandite.

W.F.F.

### Fluorine oxyapatite

### Alkaline oxyapatite

V. I. VLODAVETZ: On two apatites of the Kukisvumchorr deposits in the Khibin Tundra. *Trans. Arctic Inst. U.S.S.R.*, **12**, 71-100, 1933. (English summary.)

Vlodavetz notes a change in the character of the apatite from the top to the bottom of the apatite ore body. The upper part is a *fluorine oxyapatite*:  $SiO_2$  0.04,  $Al_2O_3$  0.33,  $Ti_2O_3$  0.68,  $Fe_2O_3$  0.20,  $MgO$  0.10,  $CaO$  54.28,  $SrO$  1.60,  $BaO$  tr.,  $Na_2O$  0.15,  $K_2O$  0.04,  $H_2O$  0.13,  $P_2O_5$  40.67,  $V_2O_5$  0.15,  $F_2$  2.79,  $Cl_2$  tr.  $G.=3.265$ ,  $\omega=1.6339$ ,  $\epsilon=1.6311$ . Birefringence=.0028. The lower part is an *alkaline oxyapatite*:  $SiO_2$  0.04,  $Al_2O_3$  0.67,  $Ti_2O_3$  0.73,  $Fe_2O_3$  0.03,  $MgO$  0.13,  $CaO$  53.54,  $SrO$  2.12,  $BaO$  0.08,  $Na_2O$  1.40,  $K_2O$  0.09,  $H_2O$  0.28,  $P_2O_5$  40.42,  $V_2O_5$  0.05,  $F_2$  1.97,  $Cl_2$  0.09. Sum 101.64.  $G.=3.259$ ,  $\omega=1.6348$ ,  $\epsilon=1.6308$ . Birefringence=.0040.

W.F.F.

### Monothermite

### Endothermite

D. S. BELANKIN: On the characteristics of the mineral monothermite. *Compt. Rend. Acad. Sci., U.S.S.R.*, **18**, No. 9, 673-676, 1938 (in English).

Monothermite is a clay mineral similar to kaolin but differing from it in its thermal behavior. Its formula is  $0.2 RO \cdot Al_2O_3 \cdot 3SiO_2 \cdot 1.5H_2O \cdot 0.5 aq$ . Analysis: (average of several)

SiO<sub>2</sub> 54.15, TiO<sub>2</sub> 1.16, Al<sub>2</sub>O<sub>3</sub> 30.72, Fe<sub>2</sub>O<sub>3</sub> 1.07, MgO 0.48, CaO 0.67, Na<sub>2</sub>O 0.58, K<sub>2</sub>O 2.74, SO<sub>3</sub> 0.13, ign. loss 8.43. At 100°C. loses 0.5 H<sub>2</sub>O, at 550° 1.5 H<sub>2</sub>O, whereas kaolin does not lose water even up to 300°–400°. Monothermite has one endothermic effect at 550° (hence the names, monothermite or endothermite) whereas kaolin has two, at 550°C. and 900°–950°C.

Index of refraction = 1.55–1.57.

Birefringence,  $\gamma - \alpha = 0.02 - 0.03$ .

Occurs in the clays of Chassov-Jar and common in Russian clays.

W.F.F.

#### DISCREDITED SPECIES

##### Cliftonite

MAX H. HEY: A re-examination of cliftonite. *Mineral. Mag.*, **25**, 81, 1938, 1 fig.

An x-ray examination of one of the type cliftonite crystals showed its identity with graphite. Cliftonite is therefore a pseudomorph after some unknown cubic mineral. The graphite crystals are arranged with their *c* axes parallel to the three (001) axes of the cube.

W.F.F.

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#### OBITUARIES

Professor G. Cesàro died at Comblain-au-Pont, Belgium, on January 20, 1939. He was born at Naples, Italy, on September 7, 1849, came to Liège, Belgium, in 1865 and taught crystallography and mineralogy at the University of Liège for forty years. He became emeritus in 1922, but continued his work of research in mineralogy, crystallography and mathematics almost to the time of his death. His list of publications numbers about 250 titles. He is survived by his nephew, Dr. J. Mélon, who has contributed articles at various times to *The American Mineralogist*.

Dr. Frank Nelson Guild, Professor Emeritus and former head of the Department of Geology and Mineralogy of the University of Arizona, died at his home, Tucson, Arizona, March 12, 1939, at the age of 68 years.

Dr. Guild had been a member of the faculty of the University of Arizona since 1897.

William Ebenezer Ford, Professor of Mineralogy and Curator of the Mineral Collections in the Sheffield Scientific School of Yale University, died on March 23, 1939, at the age of 61 years.